# *JOURNAL of the* AMERICAN SOCIETY *of* *NAVAL ENGINEERS* Inc.

February, 1961

Volume 73 Number 1

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# AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

REAR ADMIRAL E. H. THIELE, U. S. COAST GUARD

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1957 **Rear Admiral Albert G. Mumma, U. S. Navy**
1958 **Rear Admiral Leroy V. Honsinger, U. S. Navy**
1959 **Rear Admiral William A. Dolan, U. S. Navy**
1960 **Rear Admiral Robert E. Cronin, U. S. Navy**

*Names in italics deceased

# JOURNAL

*of*

# The American Society of Naval Engineers, Inc.

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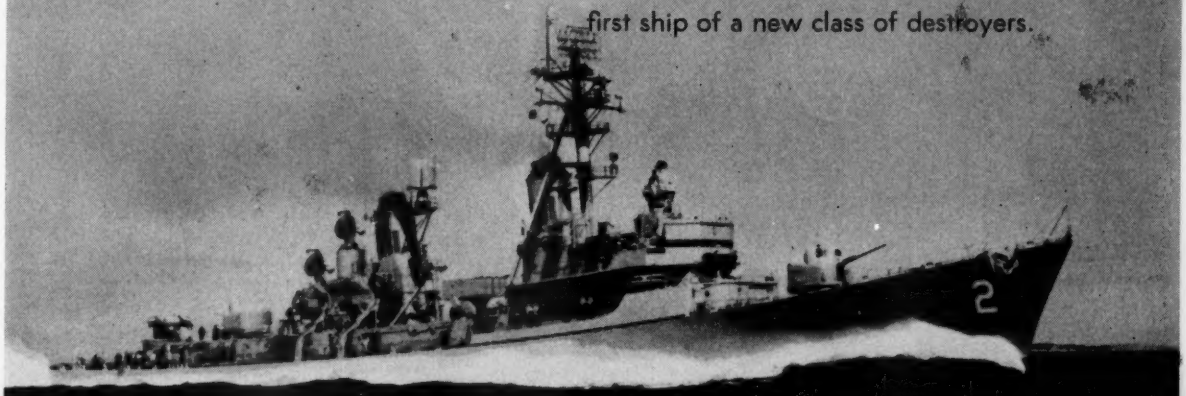


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# *Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.*

VOLUME 73 FEBRUARY 1961 NUMBER 1


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(Under whose supervision this number is published)

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Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer


## NAVAL ENGINEERING

**Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.**

### 1960 Election

On 4 January 1961, at a Joint 1960-1961 Council meeting, the report of the ballot counting committee was submitted. After accepting this, Admiral Cronin declared that the following had been elected:

Rear Admiral E. H. Thiele, U.S. Coast Guard, to succeed Rear Admiral R. E. Cronin, U.S. Navy as President for 1961.

Rear Admiral Floyd B. Schultz, U.S. Navy, Regular naval Council member for 1961 and 1962 to succeed Captain T. W. Rogers, U.S. Navy (Ret.).

Captain Edward J. Fahy, U.S. Navy, Regular naval Council member for 1961 and 1962 to succeed Commander J. A. Coil, U.S. Navy.

Captain Gilbert F. Schumacher, U.S. Coast Guard, Coast Guard member of the Council for 1961 and

**Joint Meeting 1960-1961 Councils Left to Right: Front Row: Mr. Hill, Council (1960-1961) Lieutenant Commander Roane, Council (1961-1962); Mr. Weber, Council (1961-1962); Admiral Cronin, President (1960); Admiral Thiele, President (1961); Captain Fahy, Council (1961-1962); Captain Schumacher, Council (1961-1962); Admiral Lawrence, Council (1960-1961); Back Row: Captain Jones, Council (1960-1961); Commander Burpo, Council (1959-1960); Commander Coil, Council (1959-1960); Commander Lorimer, Council (1959-1960); Mr. Frankel, Council (1959-1960); Captain Hamilton, Secretary-Treasurer. Absent and not included on the picture: Captain Rogers, Council (1959-1960); Admiral Schultz, Council (1961-1962); Commander Thornbury, Assistant Secretary-Treasurer.**

1962 to succeed Rear Admiral E. H. Thiele, U.S. Coast Guard.

Lieutenant Commander C. P. Roane, U.S. Naval Reserve (Ret.), naval reserve member of the Council for 1961 and 1962 to succeed Commander R. S. Burpo, U.S. Naval Reserve.

Mr. C. Swan Weber, Civilian member of the Council for 1961 and 1962 to succeed Mr. Gilbert S. Frankel

As a result of the election, the Council of the Society for 1961 will be constituted as shown in the masthead on page 7.

**By-Laws Change**

The proposed By-Laws change, by which the former Junior membership is retitled Student membership and a new class of Junior membership available to candidates under 30 years of age is established, was adopted by the members by a vote of 1229 to 53.

The Council is empowered to establish a list of accredited schools for the Student membership and the amount of dues for both Junior and Student members. This matter was taken up at a Council meeting held on 7 February. The following are accredited schools at which any undergraduate may be eligible to apply for Junior membership in the Society. Suggestions from any member as to changes in this list are solicited by the Council.

Akron, University of (Akron, Ohio); Alabama, University of (University, Alabama); Alaska, University of (College, Alaska); Arizona, University of (Tucson, Arizona); Arkansas, University of (Fayetteville, Arkansas); Bradley University (Peoria, Illinois); Brooklyn, Polytechnic Institute of (Brooklyn, New York); Bucknell University (Lewisburg, Pennsylvania); California Institute of Technology (Pasadena, California); Carnegie Institute of Technology (Pittsburgh, Pennsylvania); Case Institute of Technology (Cleveland, Ohio); Catholic University of America (Washington, D.C.); Cincinnati, University of (Cincinnati, Ohio); Citadel, The (Charleston, S.C.); Clarkson College of Technology (Potsdam, New York); Clemson Agricultural College (Clemson, S.C.); Colorado A&M College (Fort Collins, Colorado); Colorado School of Mines (Golden, Colorado); Connecticut, University of (Storrs, Connecticut); Cooper Union School of Engineering (New York, New York); Dayton, University of (Dayton, Ohio); Delaware, University of (Newark, Delaware); Denver, University of (Denver, Colorado); Detroit, University of (Detroit, Michigan); Drexel Institute of Technology (Philadelphia, Pa.); Fenn College (Cleveland, Ohio); Florida, University of (Gainsville, Florida); George Washington University (Washington, D.C.); Hawaii, University of (Honolulu, Hawaii); Houston, University of (Houston, Texas); Howard University (Washington, D.C.); Iowa, State University of (Iowa City, Iowa); Johns Hopkins University (Baltimore, Maryland); Kansas State College (Manhattan, Kansas); Kentucky, University of (Lexington, Kentucky); Lafayette College (Easton, Pennsylvania); Lehigh University (Bethlehem, Pennsylvania); Louisiana Polytechnic Institute (Ruston, Louisiana); Louisiana State University (University, Louisiana); Lowell Technological Institute of Massachusetts, Formerly Lowell Textile Institute (Lowell, Massachusetts); Maine, University of (Orono, Maine); Manhattan College (New York, New York); Maryland, University of (College Park, Maryland); Massachusetts Institute of Technology (Cambridge, Mass.); Massachusetts, University of (Amherst, Massachusetts); Michigan College of Mining and Technology (Houghton, Michigan); Michigan State College (East Lansing, Michigan); Mississippi State College (State College, Mississippi); Missouri School of Mines and Metallurgy (Rolla, Missouri); Montana School of Mines (Butte, Montana); Montana State College (Bozeman, Montana); Nevada, University of (Reno, Nevada); New Hampshire, University of (Durham, New Hampshire); New Mexico College of A. and M. Arts (State College, N.M.); New York, City College of (New York, New York); New York State College of Ceramics (at Alfred University) (Alfred, New York); New York University (New York, New York); Newark College of Engineering (Newark, New Jersey); North Carolina State College (Raleigh, N.C.); North Dakota Agricultural College (Fargo, North Dakota); North Dakota, University of (Grand Forks, N.D.); Northwestern University (Evanston, Illinois); Norwich University (Northfield, Vermont); Ohio University (Athens, Ohio); Oklahoma A&M College (Stillwater, Oklahoma); Pittsburgh, University of (Pittsburgh, Pa.); Pratt Institute (Brooklyn, New York); Rhode Island, University of (Kingston, Rhode Island); Rose Polytechnic Institute (Terre Haute, Indiana); Rutgers University (New Brunswick, N.J.); Saint Louis University (St. Louis, Missouri); Santa Clara, University of (Santa Clara, California); South Dakota State College (Brookings, S.D.); South Dakota School of Mines (Rapid City, S.D.); Southern Methodist University (Dallas, Texas); Stevens Institute of Technology (Hoboken, New Jersey); Swarthmore, College (Swarthmore, Pa.); Syracuse University (Syracuse, New York); Tennessee, University of (Knoxville, Tennessee); Texas, A&M College of (College Station, Texas); Texas College of Arts and Industries (Kingsville, Texas); Texas Technological College (Lubbock, Texas); Texas Western College (El Paso, Texas); Toledo University (Toledo, Ohio); Tulsa, University of (Tulsa, Oklahoma); Union College (Schenectady, New York); Utah State Agricultural College (Logan, Utah); Vermont, University of (Burlington, Vermont); Virginia Military Institute (Lexington, Virginia); Virginia Polytechnic Institute (Blacksburg, Virginia); Washington, State College of (Pullman, Washington); Washington University (St.

Louis, Missouri); Wayne University (Detroit, Michigan); West Virginia University (Morgantown, W.Va.); Wichita, Municipal University of (Wichita, Kansas); Worcester Polytechnic Institute (Worcester, Massachusetts); Wyoming, University of (Laramie, Wyoming).

Dues were established
For Junior Members at $6.00
Student Members at $3.00

**Adjustments of Present Memberships**

Without any action by the member, the accounts of all present Junior Members will be adjusted as of 1 January 1961 to the Student member rate and their designation will be changed from Junior to Student members.

On the written request of any Naval, Civilian or Associate member whose 30th birthday will not occur before 1 January 1963 his status will be changed to Junior member as of 1 January 1961. It will be noted that this change for Naval and Civil members entails relinquishment of voting rights and eligibility for office in the Society. Member's date of birth must be stated in the request.

On the first of January of the year following graduation or other separation from school, each Student member will automatically become a Junior member and will be obligated for dues at the Junior rate.

At the same time any Junior member who reached his 30th birthday during the preceeding year will automatically become a Naval or Associate member as appropriate and will be obligated for dues at the full rate.

**Society's Finances**

The 1960 results were a little more favorable than had been predicted. A financial statement as approved by the Auditing Committee is published in the Association Notes of this issue.

The Council has approved the following operating budget for 1961.

| | | |
|---|---|---|
| **Income** | | |
| Dues | 33500.00 | |
| Advertisements | 12400.00 | |
| Sales | 600.00 | |
| Subscriptions | | |
| Contract | 10000.00 | |
| Domestic | 2000.00 | |
| Foreign | 4000.00 | |
| Interest | 2600.00 | |
| Banquet | 1000.00 | 66,100.00 |
| **Expenditures** | | |
| Journal | 34000.00 | |
| Salaries | 18200.00 | |
| Retirement | 3300.00 | |
| Awards | 450.00 | |
| Rent | 3100.00 | |
| Social Security | 500.00 | |
| General Expense | 5000.00 | |
| Depreciation | 400.00 | |
| Contingent | 1000.00 | 65,950.00 |
| Net gain | | 150.00 |

**ASNE Staff**

The Council on 4 January 1961 approved the continuance of the following staff for 1961.

Secretary-Treasurer: Captain J. E. Hamilton, USN (Ret.)
Assistant Secretary-Treasurer: Commander Joe W. Thornbury, USN
Administrative Director: Miss Ruth M. Leonard
Assistant to the Administrative Director: Mrs. T. J. Ellis

**The ASNE Gold Medal Award—1960**

Members of the Society are aware of the fact that an annual award is available each year to that citizen of the United States who made the greatest contribution to the advancement of NAVAL ENGINEERING during the year.

The awardee is selected by a board consisting of three past-Presidents of the Society (assuming that we can assemble this many) from their own knowledge (secondary) and primarily from the citations which are received.

Initially to establish a firm criterion, an official definition of Naval Engineering was adopted. This definition has appeared under the masthead in each issue of the JOURNAL since its adoption.

This is a recently etablished award and has been made only twice to date. For 1958 the award was made to Mr. Valor C. Smith of the Naval Electronics Laboratory for his contribution in connection with radio antenna design. The 1959 award was received by Dr. Waldo K. Lyon, also of the Naval Electronics Laboratory for his contribution in connection with the development of electronics equipment particularly applicable to submarine operations in Arctic waters.

The Society wants this, its major award, to gain recognition as one of the most important awards in the world for technical achievement. It is intended to be just this. This fact makes it very difficult for executives to recommend their own people for the award for several reasons, including:

Many accomplishments are the result of joint effort and it is difficult to single out an individual for specific credit;

Where, in the opinion of the executive, several things of note have been accomplished, he hesitates to select one as the most important because of fear of an adverse morale effect;

He makes a prejudgment that someone will be cited by someone else whose feat will be considered more outstanding than the best that he has to offer;

The outstanding accomplishments of which he is aware probably are not (in his opinion) within the field of Naval Engineering and

Security reasons.

We have tried by display presentations in the JOURNAL and by personal letters to selected Naval Commanders to encourage the submission of cita-

tions for this award. To date the response has been very light. The awards committee is convinced that many more things, worthy of consideration are done each year than are placed before them for selection. To what extent this may have colored decisions during the last two years is indeterminate. The committee has no way of evaluating an accomplishment of which it is ignorant.

What has been accomplished during 1960? We can cite continued submarine operations in the Arctic, successful test firing of the POLARIS missile from *George Washington* and *Patrick Henry*, and launching the world's largest ship, the nuclear powered aircraft carrier *Enterprise*. These are a few of the end products of Naval Engineering during 1960. They are outstanding because of singular contributions to the field of Naval Engineering in 1959, 1958, 1957 etc. What has been done during 1960 which will make it possible for the realization of outstanding results in 1961, 1962, 1963 etc.? These are the things that we are looking for as well as the 1960 accomplishments which had a final payoff within the same year. This is the sort of judgment which is within the capacity of Naval Engineering executives to make.

Please Note:
Anyone can submit a citation
Any American Citizen may be cited
Naval Engineering is a very broad field
There need be no administrative relationship between the citer and the citee

Awards may be submitted up to 15 March 1961, about two weeks after you receive this Journal. Was anything accomplished during 1960. Was it outstanding, in your opinion? Do you know who did it? Do you see any connection whatever between this thing and Naval Engineering? Can you describe the accomplishment and the relationship of the man to the deed?

If each reader who sees this can answer all questions affirmatively he owes us a citation for a proposed recipient of the 1960 ASNE Gold Medal Award. Please send it to—

ASNE Award Committee
American Society of Naval Engineers
Suite 403
1012 14th Stret, N.W.
Washington 5, D.C.

Typewriting is preferred but legible handwriting is fuly acceptable.

**1961 Banquet**

Plans for the 1961 banquet to be held at the Statler Hilton Hotel, Washington, D.C. on Friday, 28 April 1961 are going forward. The principal speaker will be Admiral J. W. (Dutch) Will, USN (Ret.), President of American Export Lines.

Notice and application forms for the banquet should reach all members very shortly after receipt of this Journal.

**A Technical Society and Technical Meetings**

This subject was discussed in the Secretary's Notes in the November 1960 issue of the Journal. It was hoped that members would submit comments and suggestions and the Council will certainly welcome any of these. The matter has been placed on the Council's agenda and was considered and discussed at a meeting on 7 February 1961. It will continue on the agenda until a decision is reached.

**Advertisements**

For the second time, our advertisers have been given more favorable, we think, locations in this issue of the Journal. We have received a little comment on this, none unfavorable and more either pro or con is desired. Members who are in a position to do so, might well call this to the attention of prospective advertisers. New users of Journal pages for advertisements to express their connection with Naval Engineering will be welcomed up to a limiting number of pages.

## For ships at sea: security

At sea, "security" is a word with a double meaning. There is the security that ships of every kind derive from modern methods of navigation. And there is the security that the nation derives from the strength of her naval fleets.

To both kinds of security, Sperry is a major contributor. Some two-thirds of the world's ocean-going commercial vessels are equipped with Sperry navigational instruments and controls: Gyro-Compasses that provide the basic true-North indication . . . automatic steering systems that "take the wheel" to hold a continuous straight course . . . sophisticated navigational radars and lorans . . . Gyrofin® ship stabilizers that counteract the very rolling of the sea . . . and for small craft, simpler yet precise navigational aids.

For our Navy – in addition to advanced systems for all nuclear submarines, including the Polaris missile fleet, Sperry equipment adds to the striking power of the surface fleet. Missile tracking radars, for instance, that are on duty with the newest guided missile destroyers, cruisers and carriers, provide acquisition, tracking and guidance for the Terrier and the longer range Talos. Or the Sperry fire control and weapon direction systems which supply missile threat evaluation displays, target selection, the best missile-to-target flight path and "kill" evaluation.

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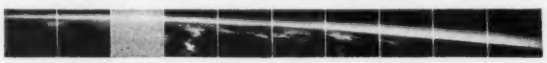

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50 YEARS 1910 1960

LIEUTENANT COMMANDER BURTON I. EDELSON, USN

# *THE ASTRONAUTICS SHIP CONCEPT*

**THE AUTHOR**

*is an engineering duty officer. He was graduated from the Naval Academy in 1947, attended the Naval Postgraduate School in Monterey and earned M.S. and PhD degrees in Metallurgy from Yale University. He served aboard ships in both the Atlantic and Pacific Fleets and is currently assigned as Head, Astronautics Section, Research and Development Systems Division, Bureau of Ships. He is a member of ARS, ASNE, ASM, and Sigma Xi. This is his third contribution to the* JOURNAL.

THE SPACE AGE dawned on 4 October 1957—the day Soviet Russia successfully placed SPUTNIK I, the first earth satellite, into orbit. Scientists, military men, and laymen throughout the entire world marvelled at this accomplishment: a 184-pound electronically instrumented package revolving about the earth 588 miles high and with a speed of up to 18,000 miles per hour, girdling the entire globe in 96 minutes! One month later the Russians orbitted another satellite, SPUTNIK II, this time with an instrumented payload of over 1100 pounds. At the end of January 1958, the United States Army placed the first American satellite, EXPLORER I, in orbit—only about 19 pounds it is true, but unlike the SPUTNIKs, it is still in orbit. Then in March of 1958, the U.S. Navy fired VANGUARD I, a baby in terms of weight too, but of very sophisticated design with an instrumented payload that since has yielded an almost inexhaustible supply of scientific data, and which is still in orbit and likely to remain there for another thousand years or so.

In the three years and more that have elapsed since these first launchings many more astronautic feats have been accomplished and earth satellites have become larger and considerably more varied in nature and sophisticated in concept. As the tremendous U.S. effort in space has matured, a substantial technology has developed in rocket motors, orbital control, space power generation, payload sensors, and telemetry. Earth satellites are no longer novelties. Whereas, until the present time, the major effort has been devoted to the attainment of basic scientific data and engineering know-how in space technology, the immediate future holds the promise of fruition of these efforts in terms of many useful capabilities. U.S. civilian and military space programs are aimed at enormous improvements in our present earthbound ability to communicate over long distances, to fix the measurements of the geoid, to navigate precisely at sea, to gain world wide meteorological information, and to conduct extensive observation and reconnaissance operations through the employment of space technology.

As a full realization of the potential which this new technology holds begins to unfold, the implications of its effect upon military operations become

clearer. Astronautics applications can no longer be confined to long range plans applicable to some indistinct tomorrow; these applications must be reflected in today's firm plans, they must be reflected in billets and budgets. The U.S. Navy has acquired a real competence in space technology and has a dynamic program underway in research and development. (See, for example, "The Navy in the Space Age" by Captains C. W. Styer, Jr., and R. F. Freitag, *Naval Institute Proceedings*, March 1960). Very soon these R&D programs will translate into fleet hardware and show in such areas as Major Electronics Procurement, Military Construction, and Shipbuilding and Conversion.

Very recently a key word has crept into the vocabulary of astronautics which is bound to have major significance for the U.S. Navy in the next few years. This word is *mobility*. Mobility applies to all phases of astronautics—to launching platforms, to booster vehicles, and to payload control. This need for mobility in astronautics has given birth to the concept of the *Astronautics Ship*.

This ship concept represents a new and heretofore unexploited integrated mission for Navy ships. The Astronautics Ship would be capable of on-board storing, assembling, testing and launching space vehicles; of guiding payloads, into orbit; of receiving satellite telemetry readout directly; of tracking and controlling satellites through orbital maneuvers; and of conducting recovery operations. Because the surface of the earth, even in the Space Age, remains 70 per cent water, a ship, as no other platform can, provides true mobility to astronautics operations.

The need of the nation's space effort for mobility is a real one and is well recognized. This need stems from many factors which fall into convenient categories for discussion.

U. S. Navy Photograph

**ARTIST'S CONCEPTION OF AN ASTRONAUTICS SHIP. This ship would be capable of storing, handling, assembling, testing, and launching space vehicle boosters, tracking and guiding satellite payloads into orbit, and obtaining telemetry readouts direct from orbitting satellites. Fully instrumented and integrated Astronautics Ships will provide required mobility to the Nation's space program.**

### LAUNCH MOBILITY

The United States now has three locations for launching space vehicles: Cape Canaveral, Florida under Air Force administration, Wallops Island, Virginia, under NASA administration, and Point Arguello, California under Navy administration. (Vandenberg Air Force Base which is primarily an ICBM base adjacent to Point Arguello has also been used as a launch site.) These sites are used for launches down the Air Force monitored Atlantic Missile Range and the Navy's Pacific Missile Range. Launching sites outside of the continental limits of the U.S. are now required and the obvious difficulties and expense involved in overseas land-based construction naturally lead to the mobility concept. Mobility in launching will serve the attainment of these goals:

a. Special orbits
b. Safety
c. Security
d. Reliability
e. Economy
f. Tactical advantage

*Special orbits*—Each satellite system has a peculiar orbit, or set of orbits, which will best serve the purposes of that system. For some systems the continental launch sites are satisfactory; for others they are either totally unsatisfactory or usable only at great inconvenience and expense. Certain satellite systems, the ADVENT Communication Satellite for example, require an equatorial orbit (i.e. an orbit in which the satellite revolves about the earth directly over the equator.) If a satellite is to be launched into an equatorial orbit from a point of origin not on the equator, a dog-leg must be added to the launching flight path to change the flight plane from one passing through the launch site to the plane of the equator. Considerable energy must be expended to reorient the initial orbit and this of course must be accomplished by means of additional instrumentation in the vehicle and at the expense of useful payload. Most current space boosters are incapable of performing such missions due to the propulsion and payload penalties involved. Launching from a location on the equator—such as from aboard ship—would be the most direct solution to the problem since the simplest, most reliable, and least expensive launch vehicles could be used. As a further advantage, an easterly launch on the equator imparts to the vehicle the maximum inertial velocity from the earth's rotation.

There are other special orbits which certain satellite systems require. The operational TRANSIT Navigation Satellite System requires a 22½° orbit for ideal world-wide coverage. Since this is less than the 28° orbit inclination attainable by an easterly launch from Cape Canaveral a dog-leg launch would be required for the TRANSIT orbit and the same arguments apply. Low angle inclination orbits, then,

U.S. Navy Photograph

**THE NAVY'S TRANSIT NAVIGATION SATELLITE. The TRANSIT System being developed by the Bureau of Naval Weapons will provide world-wide, all-weather, precise navigation information to ships at sea. Optimum geographical coverage with the minimum number of satellites requires special orbital inclinations attainable only at great expense from existing continental U.S. launching sites. For several satellite systems such as TRANSIT a mobile launching capability will provide economy and reliability.**

are merely a less severe case than that of the equatorial orbit. Again a shipboard launch would result in a great advantage.

Other satellite systems require polar orbits for optimum coverage. Here, a nearly North or South launch is required. For safety reasons as noted below, this is not permitted at several U.S. launch sites. In the open ocean a North or South launch would be quite feasible.

*Safety*—In launching a satellite, multi-stage booster vehicles are employed. All but the final stage normally burn out and drop to the earth's surface without being completely consumed in the process. For obvious reasons, this cannot be allowed to occur over an inhabited region. For this reason alone, aside from the problems of celestial mechanics concerned with attaining special orbits as mentioned previously, certain trajectories are not permissible. An easterly launch from Point Arguello, or a launch due North from Cape Canaveral, for example, would certainly not be permissible. A good example of this danger occurred in the 30 November 1960 TRANSIT launch from the Cape, where an international incident was provoked by Cuban claims of vehicle fragments dropping on their territory. For similar reasons, true vertical probes cannot be fired from continental sites due to the danger of damage on return to earth. A mobile launch, however, could obviate these problems.

An entirely different aspect of safety will be introduced with the advent of nuclear rockets. A mobile launch of ROVER and other nuclear-powered rockets could avoid the real problem of radiation hazards to populated land areas.

*Security*—Mobility may provide freedom from unwanted observers in such cases where military security dictates that this is desirable. But, on the other hand, security is two-faced. Mobility may provide complete freedom from security restrictions where such is desired. This concept may open up an entirely new avenue of technical diplomacy. With a sea launch capability joint scientific programs can be established with foreign governments, with foreign scientists providing the satellites and the United States providing the vehicles and the sea launch sites. Such a program would further international good will and support confidence in U.S. technical competence.

*Economy*—A mobile launch capability would be economical from several standpoints. Foremost is the savings in dollars which would accrue from the opportunity to use the simplest launch and control techniques to attain special orbits. When guidance and control systems may be simplified, higher reliability results. All of these factors help to reduce cost: the simplification of control and guidance; the increase in payload for a particular booster, or use of a smaller, less expensive booster for the same payload; and the decreased need for equipment and functional redundancy made possible by increased system reliability. A secondary economy in the case of a naval shipboard launch would be attained through the at least partial use of military personnel as technicians and the elimination of need for expensive civilian security police forces.

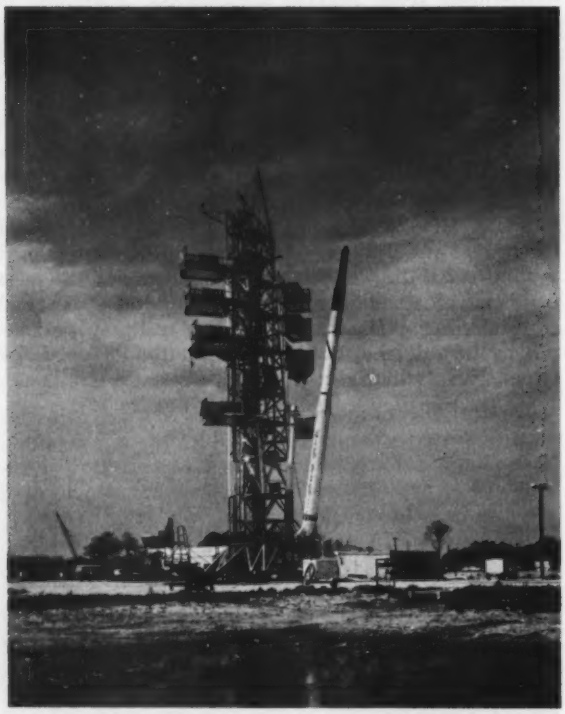
*Tactical advantage*—In the years to come as astronautics systems come to be employed on an operational basis, launching mobility will provide the responsive capability needed for tactical probes and satellite launchings coupled with a greater degree of freedom from overt enemy countermeasures.

### BOOSTER VEHICLE MOBILITY

The Nation's space program has until very recently employed military ICBM rockets as booster vehicles. All of these—ATLAS, TITAN, THOR, etc.—are liquid fuel rockets not particularly adaptable for many reasons to being transported, erected, and launched without a tremendous backup of ground support equipment for handling, fueling, and checking. In other words, these booster vehicles are not mobile. Very early in the Fleet Ballistic Missile development program the Navy recognized this limitation and commenced development of POLARIS, the first big solid fuel booster. Short, squat, and compact (only 28' long), POLARIS is the very essence of mobility, but has so far been limited to warhead instrumentation and has not been adapted to serving as a space vehicle booster.

Encouraged by the success of POLARIS, the National Aeronautics and Space Administration has developed SCOUT, a solid fuel four-stage space booster which was successfully launched in the Fall of 1960. Because it costs less than a million dollars, SCOUT has been referred to as "the poor man's space vehicle." The Air Force has recently flown BLUE SCOUT, a more powerful military version. While considerably more mobile than liquid boosters because of their length (72'), the SCOUT vehicles are still not ideal for shipboard use.

With full appreciation of the need for maximum mobility and the advantages of shipboard launch, the Navy has proposed a marriage of POLARIS and SCOUT to serve as the ideal mobile space booster. The Bureau of Naval Weapons is planning the union of the first two stages of POLARIS with the third and fourth stages of SCOUT into a new version to be known as SEA SCOUT, a vehicle especially configured for the demanding requirements of mobility and shipboard handling.



NASA Photograph

**SCOUT Space Vehicle—Known as the "Poor Man's Space Vehicle" since it will cost only about $1 million per shot, SCOUT is a four-stage solid fuel vehicle developed by the National Aeronautics and Space Administration. SCOUT will be capable of placing many operational satellites such as Navy's TRANSIT into orbit. The NASA version shown here in the launch position measures 72' overall and is too unwieldy for optimum mobility. The Navy's version known as SEA SCOUT combines the first two stages of POLARIS with the third and fourth stages of SCOUT, has the same potential payload capability but measures only 42' and is ideal for shipboard handling and launching.**

### MOBILE SATELLITE CONTROL

Earth Satellites circle the globe in many and varied orbits. These orbits are dictated by the tasks to be accomplished by the various satellites, and vary as to altitude and velocity, orbital inclination and eccentricity. Satellites are traced in these orbits by tracking stations on earth. Tracking may be accomplished by many means: optical, radar angle pointing, radio doppler, interferometry, and others.

Satellites also carry instrumented payloads which transmit measured data back to earth by radio means. This process is known as telemetry.

Certain payloads contain instrumentation which reacts upon the receipt of radio signals from the earth. These signals may cause the satellite to respond to these signals by actuating measuring devices, by initiating certain signals of its own, or by maneuvering in orbit in response to the release of gas in its control motors. This process is normally known as satellite command control.

All of these processes—tracking, telemetry, and control, often referred to as TT&C—require stations on the surface of the earth. Because satellite orbits are so varied, many TT&C stations are required on the earth's surface and the U.S. space program has spawned a network of such stations throughout the world with many more under construction. These stations are complex and costly. Because certain stations may be needed for only temporary use and because stations are frequently needed where no convenient land base is available, the TT&C function lends itself readily to the mobility concept.

Actually, this need for mobility is already recognized, and mobile TT&C stations actually exist on specially instrumented vans and on the Atlantic and Pacific Missile Range tracking and recovery ships. In this connection, the recovery function is worthy of special mention, since the recovery of re-entry vehicles is one process which actually demands mobility. For this function it is necessary to track that part of the payload which re-enters the earth's atmosphere and descends to the earth's surface to its final impact point for the purpose of capturing the information which is contained in the re-entry body. In addition, with the mounting expense of rocket engines first stage recovery may soon be a practical need.

### THE ASTRONAUTICS SHIP

The previous sections have discussed the need of the Nation's space effort for mobility in launching, in booster vehicles, and in tracking, telemetry, control, and recovery. It is particularly important to note that the Nation's, and not merely the Navy's, program substantiates this need. Although the Navy may, and in fact does, have peculiar requirements for astronautics systems as exemplified by its own development effort in navigation, communications,

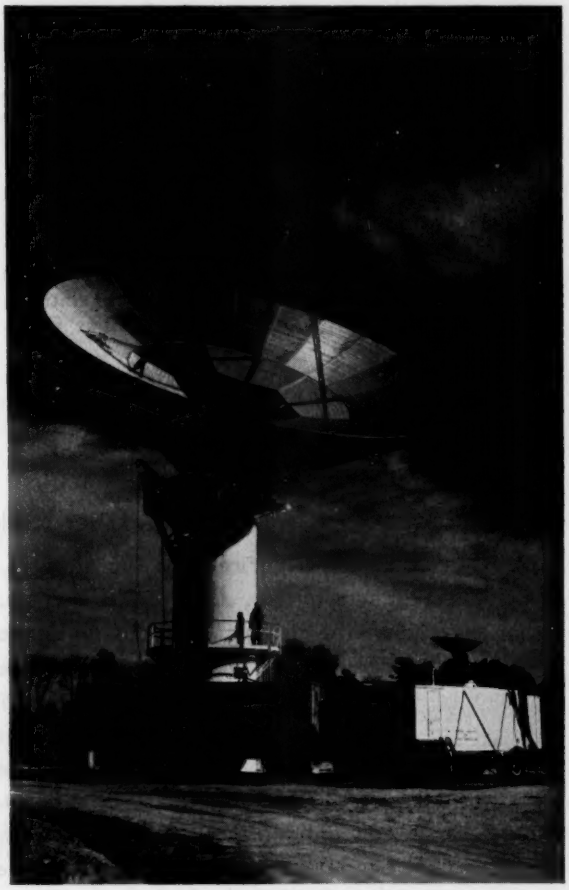
and meteorological satellites, the need for mobility in astronautics operations is not by any means confined to the Navy but extends to programs of all military services and the NASA. The Navy does, however, have certain special abilities and competence in sea operations which make it ideally equipped to assume responsibility for meeting mobility requirements. The concept of the Astronautics Ship will meet many, if not all, of the requirements for mobility in space operations.

A ship in many respects is the ideal platform for astronautics operations, being truly mobile and self-contained. It can take a launch complex and all the apposite ground support equipment and personnel to sea and remain in a remote location for long periods of time. Shipboard launching is feasible. The operations of several POLARIS submarines, of *Observation Island,* and of *Norton Sound* have amply demonstrated the launching capability. AMR and PMR ships have likewise demonstrated the feasibility of shipboard TT&C and recovery aspects of astronautics operations. What has never been done, and what next needs to be done in the Navy's astronautics program, is the design and construction of an integrated Astronautics Ship, one combining the capability of all astronautics operations in a single, sea-going, tactically-useful platform.

A ship of the size and with the accomodations and performance characteristics of a sea plane tender (AV) would be ideally suited for an Astronautics Ship and this is currently under study in the Bureau of Ships. Such a ship would have the speed and seakeeping ability necessary to operate effectively in navigable waters throughout the world; it would have commodious accommodations for the crew and technicians required; it would have space on the fantail for safe and useable launching pads; and it would have vehicle storage and handling facilities, shops, laboratories, and storerooms aplenty. Such a ship could readily mount the large radar tracking and microwave communications antennas and the smaller telemetry antennas required. Moreover, a ship of this size could easily be fitted with helicopter and boat facilities for recovery operations.

Ideally, the Astronautics Ship will be fitted with SEASCOUT space vehicles especially configured for shipboard use. It would also be able to store, handle, erect, checkout, launch, and control other solid fuel vehicles such as SCOUT, BLUE SCOUT, MINUTEMAN, if and when desired. High altitude probes such as AEROBEE and ASTROBEE could be carried and launched either for operational or scientific purposes.

Were size the only consideration, large liquid fuel boosters of the TITAN, ATLAS, and THOR class could be launched from the Astronautics Ship. However, the time-consuming and hazardous fueling operations associated with liquid boosters militate against any quick response tactical capability and thus against real mobility, at least in the present state of liquid fuel technology. There is, however, a ready and fully compatible solution to the problem of providing a considerable degree of mobility for the very largest liquid boosters. This answer lies in the use of drydocks as mobile launching platforms as proposed by the Bureau of Yards and Docks. A drydock can provide an excellent launch pad, reasonably mobile, and large enough to accomodate the very biggest space boosters, even including SAT-



NASA Photograph

**Satellite Tracking Antenna—A network of satellite tracking, telemetary, and control stations is required throughout the world in order to carry out orbital operations and collect scientific data for the Nation's Astronautics program. The stattion shown here was installed at Wallops Island Virginia by the Massachusetts Institute of Technology for the National Aeronautics and Space Administration and includes a 60′ dish and instrumented vans containing transmit receive, timing, and data recording equipment. The smaller dish mounted atop the van to the right is used for acquisition purposes. Shipboard installation of tracking, telemetry, and control equipment is part of the Astronautics Ship concept and provides needed mobility to these functions.**

URN, NASA'S 1.5-million-pound thrust vehicle scheduled for operational flight in 1963. Drydocks could be employed as vehicle transports, towed to the launching area, moored fast to the bottom if necessary, and then readied for launching. Crane service to provide necessary erection assistance would be available in the dock.

The Astronautics Ship and Drydock Launch concepts are entirely compatible. Where the dock provides the launching pad, the ship, already fitted for such purposes and anchored in the vicinity, provides the needed support in terms of hotel accomodations, special power, shops, laboratories, checkout facilities, range safety, and tracking, telemetry and control.

SUMMARY

With the existing needs and easily predictable future requirements of the Nation's space program for mobility in all phases of astronautics operations, the Navy finds itself in a unique position to assume a new and challenging mission. This mission is to provide true mobility to astronautics—in launching, in booster vehicles, in tracking, telemetry and control, and in recovery operations. This mission can be carried out through the integrated capabilities of the Astronautics Ship.

## Safety and Nuclear Propulsion Costs

The paper read on October 25, 1960, to the Institute of Marine Engineers by Mr. J. A. Dodd and Mr. S. Macdonald entitled "Observations on the design and construction of the n.s. *Savannah*" was much concerned with the features of the design necessitated by safety considerations and it was not surprising, therefore, that a good part of the discussion which followed dealt with the impact of nuclear ship safety on the cost of such a ship. It would appear that there is general acceptance that there is little likelihood of a nuclear ship reaching economic parity with conventional propulsion in the foreseeable future, and this would seem to be due primarily to disparity in capital costs. There is a strong school of thought that the high capital cost of any projected nuclear ship is caused mainly by the demand for "absolute safety" and that if this demand were relaxed something approaching economic parity with a conventional ship could be attained. Voices are now being raised in favour of such a relaxation of safety requirements, particularly by those who are frustrated by the stranglehold of financial considerations on the development of nuclear propulsion for merchant ships. Designers of ships propelled by conventional machinery are free to seek economies in capital cost, fuel consumption, space, weight, and maintenance costs provided that these economies are compatible with the maintenance of an adequate standard of safety. This standard of safety is certainly not "absolute," and certain proponents of nuclear propulsion suggest that they are victims of discrimination. The consequences of a nuclear mishap are, however, of such enormously greater magnitude that the stringency of safety standards must be correspondingly greater. Futhermore, a single incident with a nuclear ship could well create a hostile climate of public opinion which would inhibit completely the development of nuclear propulsion.

—SHIPBUILDING AND SHIPPING RECORD

RALPH A. MILLER

# *THE CENTENARY CELEBRATION OF THE ROYAL INSTITUTION OF NAVAL ARCHITECTS*

EDITOR'S NOTE: *At a meeting which began in London, England, on 17 May, 1960, The Royal Institution of Naval Architects celebrated its one hundredth anniversary. Mr. Ralph A. Miller, as a longtime member of the Institution planned to attend the Centenary and as a member of ASNE, was appointed by The Council, to represent this Society to present our greetings. (See page 200 of the May 1960 issue of the* JOURNAL.)

*Mr. Miller submitted a detailed report of the meeting, supported by considerable documentation. It was impossible to include the entire report in the* JOURNAL *because of space limitations. The following is the editor's condensation of Mr. Miller's very thorough and complete report.*

I FIRST WISH to express my appreciation to the Officers and Council of our Society for appointing me as our Society's Delegate to the Centenary Celebration of the Royal Institution of Naval Architects; an honor and privilege that I cherish.

The Celebration opened on May 17, 1960, with an Informal Reception by the President of The Royal Institution of Naval Architects, Viscount Runciman of Doxford, O.B.E., A.F.C., D.C.L., and Viscountess Runciman, in the Foyer of the Royal Festival Hall, followed by Luncheon, and later, by an Organ Recital.

After some 600-700 Members and Guests had gathered in the main hall, and following a short introduction by the President, Lord Doxford, H.R.H. Prince Philip opened the Meeting. He recalled that he had served at sea with the errors and mistakes made by naval architects, and was now in the enviable position of having these naval architects at his mercy, but that he would forego his vengeance. Although the Membership of The Royal Institution of Naval Architects is world-wide, (some 30 per cent residing abroad), it is basically a British institution, and to the British the Prince warned against complacency regarding competition from other shipbuilding countries, and other modes of transportation. He also mentioned the challenge of such matters as vibration, economy, heavy-weather speed, methods of construction, cargo handling, manpower, etc. He stated that he was sure that the

Institution would continue its outstanding efforts of the past century and that a climate of vigorous progressiveness and the hope of exciting developments in the challenging profession of Naval Architecture were needed to attract the high calibre men essential for progress.

There followed the presentation of gifts and mementoes of the occasion—from a number of learned societies and associations.

Rear Admiral A. G. Mumma, USN (Ret), president of the Society of Naval Architects and Marine Engineers and past-president of ASNE, presented an iluminated parchment Greeting from the former society. Ralph A. Miller, Esq., presented this Society's engrossed Greetings in a blue simulated leather case with gold stampings, lined with yellow-gold colored grosgrain cloth.

Two technical Papers were then presented in brief abstract, accompanied by moving pictures and slides. Condensations of these Papers follow the general account of the Celebration. The first Paper was entitled: "Warships 1860-1960" by A. J. Sims, O.B.E., R.C.N.C. (Member of Council of R.I.M.A.), Director General Ships, Admiralty. The second Paper was entitled: "Merchant Ships 1860-1960," by J. M. Murray, M.B.E., B.Sc. (Vice President, R.I.N.A.), Chief Ship Surveyor, Lloyd's Register of Shipping.

That evening a Reception was given by Her Majesty's Government at Lancaster House, St. James, for Official Delegates, Foreign Members and Ladies. The Rt. Hon. the Lord Carrington, K.C.M.G., M.C., First Lord of the Admiralty, and Lady Carrington, received the guests. Following this Reception, Official Delegates and Ladies were dinner guests of the President and Members of the Council of the R.I.N.A. at Claridges.

On Wednesday morning, May 18, 1960, we left Charing Cross Pier by river boats for Greenwich. It was a cloudy, cool, cheerless day that caused many to go below. Points of interest along the way were announced by loud speakers. On arrival at Greenwhich we boarded *Cutty Sark,* built in 1869, the last surviving clipper ship in the world. She is in a special dry dock, and with reasonable maintenance, should last indefinitely. She has fine lines, being built as a fast tea clipper, but carried an enormous spread of canvas, and has made up to 17½ knots by hand and patent log. The hull is of composite construction, so that copper sheathing could be fitted to keep a clean bottom on the long voyage from England to China and back around the Cape of Good Hope.

Greenwich is undoubtedly best known for its selection in 1884 as the zero meridian of longitude by an International Agreement, and consequently, the "home" of Greenwich Mean Time (G.M.T.); it being the site of the Royal Observatory founded by Charles II in 1675. The growth of London, and of nearby industry so polluted the air, and the fitting

**"Mr. Miller (right) presents ASNE greetings to Lord Doxford, President R.I.N.A.**

of brighter street lighting, rendered Greenwich no longer suitable for celestial observations. The Observatory was, therefore, moved to Herstmonceux Castle in Sussex, not far from where the Battle of Hastings was fought. Greenwich remains the zero meridian, however, and Time is still measured from Greenwich.

About 1428 (the year Joan of Arc went to the French Court) the Duke of Gloucester, while Regent for young King Henry VI, built a small castle with a watch tower on the hill where stands the building formerly housing the Royal Observatory. He also built a small palace nearby, on the banks of the Thames. It was later named "Placentia," a favorite home of successive Royal families, who enlarged it from time to time. Both Henry VIII and Elizabeth I were born here, and it is here that Sir Walter Raleigh is said to have spread his cloak so that she could cross the muddy road with clean shoes. Queen Elizabeth, is said to have lavishly furnished Greenwich so as to impress Ambassadors with the wealth (and thus, the might) of England. James I built a house here for his Queen, Anne of Denmark—a gem of Palladian architecture—which is still known as the "Queen's House." It spanned the then muddy road so that the Court could cross the road without getting muddy. This house is of great architectural importance, as here Inigo Jones introduced a new concept of room arrangement that was followed by country seats all over England.

Unfortunately, Placentia Palace was destroyed because of abuse and neglect during the Cromwell rebellion, and the Queen's House is now the oldest building. One of the present buildings dates from the reign of Charles II, and the rest of the main buildings from the reign of William and Mary, though many years passed before all were completed. Sir Christopher Wren designed them. Greenwich was used as a hospital for disabled and aged Naval pensioners until 1869. In 1873 it became the Royal Naval College, to provide for the "Education

of Naval Officers . . . . . in all branches of theoretical and scientific study bearing upon their profession." The Naval School of Naval Architecture at South Kensington was moved to Greenwich, where members of the Royal Corps of Naval Constructors have since been trained. The Painted Hall was originally intended to be the refectory of the hospital, but was not regularly used as such. Since 1939 the Painted Hall has served as the Officers' Mess. The assertion that it is the most beautiful Officers' Mess in the world is undoubtedly true. Sir James Thornhill required nineteen years to produce the beautiful paintings covering its walls. It contains a marble slab commemorating the three U. S. Naval Officers who served the Royal Navy before our entry in World War II.

In 1937, King George VI opened The National Maritime Museum in these buildings, to illustrate the Maritime History of Great Britain; Naval, Merchant, and Fishing. The Queen's House contains pictures, models, and relics of the 16th and 17th centuries. Exhibits are continued in the Caird Galleries, the Navigation Room, Neptune's Hall, the East Wing, and the Print Room, which has over 10,000 prints, several thousand marine drawings, and a large collection of photographs and cuttings. Neptune's Hall has a great number of scale models of ships of the 19th and 20th centuries. Adjoining Neptune's Hall is the Barge House, with four original state barges, one being the Queen's shallop of 1689, and another being Prince Frederick's barge of 1732. The Museum preserves a fine astrolabe given by Queen Elizabeth I to Sir Francis Drake in 1581, after his return from his trip around the world in *Golden Hind.*

We were guests of the National Maritime Museum during the visit to the Museum, and were guests of The Shipbuilding Conference for luncheon in a marquee near the Queen's House. After completing the tour, we returned to London by motor coach.

On Thursday morning, May 19, 1960, we went to Stratford-on-Avon by a special train, drawn by a "special" engine, the "Evening Star." This engine, designed for heavy freight traffic, was completed in March 1960, and is scheduled to be the last steam locomotive to be built for British Railways, thus marking the beginning of the end of the era of British steam railway traction that started in 1825. Although steam is by no means *passé* in ships, it seems appropriate that the engine closing an era of land transportation should move us while we were celebrating the end of our first century of service to water transportation. Luncheon was served en route at our seats, there being a kitchen car but no dining car.

We visited the new Ship Hydrodynamics Laboratory of the National Physical Laboratory at Feltham on Friday, May 20, 1960, by motor coach. Feltham is about 12 miles Southwest of the center of London, and about 5 miles Northwest from the old Laboratory at Teddington.

The Ship Division of the National Physical Laboratory was started in 1908 by a gift of £20,000 by Sir Alfred Yarrow for the building of a towing tank. This tank is 500′×30′×12.3′ and was completed in 1911. A second tank, 680′×20′×9.3′ was completed in 1932. At this time, Sir James Lithgow donated £5,000 for a propeller water tunnel to study cavitation. These facilities became inadequate by 1945 and plans for new tanks were made. A main tank, 1800′×50′×25′ was desired, but available funds reduced the size to 1300′×48′×25′. Due to soil conditions, the tanks are above ground, thus necessitating an unusually high building for the main tank. Arrangements are made to keep the water temperature at about 60°F. Models up to 5 tons weight and 40 ft. length can be towed. The highest carriage speed is 50 ft/sec. The tank has a wave-maker at one end. The water tunnel is one of the largest, and is designed to test propellers up to 24″ diameter, with water speeds of 50 ft/sec. The seakeeping tank is 100′×100′×8′, with a wave-maker and a beach. Models may be 10 ft long, and are radio controlled. The extreme precision of this control was shown when a model left the pier, maneuvered in waves, and gently landed alongside the pier. Special devices are being developed to record the model's position at all times. A small tank has a wavemaker for irregular waves. Vibration studies are made in a tank 20′×14′×6′.

There are the usual shops making propellers, models, etc. A large self propelled wax model of the new *Canberra* of the Peninsular & Oriental Steam Navigation Co. was on display. This model showed a pronounced bulb extending forward of the stem, and the propeller shafting is supported by struts in lieu of the bossings usually fitted to merchant ships.

During the visit, Lord Doxford presented the Gold Medal of the Royal Institution of Naval Architects to the Ship Division, National Physical Laboratory, praising the half-century service of the Ship Division to the Marine Industry. Dr. F. H. Todd, Superintendent of the Ship Division, accepted the Gold Medal for and on behalf of the Laboratory. Dr. Todd served as Technical Director, Hydrodynamics Laboratory, at the David Taylor Model Basin for some years. Luncheon was served in a marquee on the grounds, and tea was served after touring the Laboratory.

The Official Banquet was held the evening of the same day, at Dorchester Hotel, Park Lane. Forty-two Ambassadors and high officials in Government and Shipping and their Ladies shared the head table with the president, Lord Doxford. We were honored by the presence of The Right Worshipful the Mayor of the City of Westminster, in which part of greater London the Dorchester Hotel is located.

Unfortunately, the Right Honourable the Lord Carrington, First Lord of the Admiralty, was unable to attend. A red-coated man with booming voice was there to make announcements. Some 530 Members, Guests and their Ladies were present.

Following the usual preliminaries and the toast to Her Majesty the Queen, the president proposed a toast to "The Guests." He said that we were nearing the end of four memorable days, but that the best of plans would have been barren and in vain but for the large and distinguished company of outstanding representatives from kindred societies and from overseas members. He particularly welcomed Monsieur A. Augustin-Normand, a member for 50 years, who had received his Diploma of Honorary Membership from the hands of H.R.H. Prince Philip several days before. Monsieur Augustin Normand decends from a French family that has built ships in direct succession from father to son since 1728.

Monsieur Augustin-Normand replied, praising the Royal Institution of Naval Architects, and mentioned that it is the mother of a number of similar Societies in other countries. He noted that the Institution had grown from the membership of 324 in 1860 to 4358 in 1960.

Although the weather was cool, mostly overcast, with some rain, the meeting was a good one. The staff of The Royal Institution of Naval Architects planned and well executed a series of interesting and informative events.

Although some 700 Members, Guests, and their Ladies registered for the Meeting, Rear Admiral Mumma and myself were the only Members from the United States whom I observed attending. I realize that very few U.S. Citizens are Members of The Royal Institution of Naval Architects.

*A condensation of the two papers which were presented on the opening day follow:*

## WARSHIPS 1860-1960

*by* A. J. Sims, Esq., O.B.E.
*RCNC, Director General Ships, Admiralty*

In addition, moving pictures of early Naval Reviews were screened, with comments regarding the ships shown.

The Author considers that much of the development of warships during the past century is due largely to the founding of the Royal Institution of Naval Architects (1860), the firm establishment of the School of Naval Architecture (1864) and the establishment of the Royal Corps of Naval Constructors (1883).

This review of a century of change considers mostly ships of the Royal Navy, with outstanding contributions by other Navies included. With this limitation, the task of compressing a century of change into one paper remains indeed formidable, and the Author is to be congratulated upon the result. This writer suggests however, that a brief discussion of the effects the advent of smokeless powder had on naval guns, and the resultant effect on warship design, is warranted; and hopes that it can be added when the paper is included in the "Transactions." Mention could also be made of the marked improvement in gunfire resulting from the adoption of telescopic rights at the turn of the century.

The changes in size and composition of the Royal Navy were graphically shown by six charts showing the ships at five actual Naval Reviews throughout the century, and an imaginary Naval Review that could be held in 1960.

The paper was divided into three sections, viz:

(i) A historical survey in relation to warship development
(ii) Development of types of warships
(iii) Selected technical developments

Only outstanding items of the Author's paper will be given in this account.

The 1845 British Naval Review was the last having all warships propelled by sail. By 1856, 21 of the 24 ships of the line had steam engines. In this Review, there appeared for the first time, iron-clad ships; 4-1,500 ton floating batteries. It was the last Review including sailing ships of war.

The British *Warrior* launched in 1860, was the first armored warship built entirely of iron.

*Miranda,* launched in 1871, can be regarded as the prototype of the Torpedo-boat. She led to the development of the Torpedo Gunboat, and later to the Torpedo-boat Destroyers.

In the latter part of the 19th century, guns advanced from six to eighteen to twenty-five tons and eventually to one hundred and ten tons, and iron armor increased from 6″ to 9″ to 12″ and eventually to 24″.

The British were slow in adopting submarines, but, with the success of *Holland* in the U.S.A. ordered five of the type in 1900.

At the turn of the century, the advent of smokeless powder permitted gun bores to be reduced from 13.5″ to 12″, and the advent of cemented steel armor allowed a reduction in thickness from 18″ for compound armor to 12″ for cemented steel armor. These developments, coupled with the advent of steam turbines, permitted great advances in warship design. *Dreadnought* was fitted to burn both oil and coal, as were other battleships prior to *Queen Elizabeth* Class. These superb ships burned oil only.

The well-known *Dreadnought* was laid down in 1905 revolutionizing battleship design.

The battle-cruiser concept was developed in 1905, the year *Dreadnought* was laid down, with three ships of *Invincible* Class. They were followed by additional classes in 1908, 1909, 1911, 1913, culminating in *Hood* during World War I. Battleship and Battle-Cruiser concepts merged in 1936 with *King George V* Class.

The *Tribal* Class of 1909 were the first British Destroyers to burn oil only.

Following the advent of cruisers in America during the War of 1861-64, the British laid down their first cruiser, *Inconstant,* in 1866. The cruiser, *Iris,* laid down 1875, was the first British warship built entirely of mild steel. There developed three classes of cruisers; the Armored, Protected, and Light Cruisers. The armored cruiser, *Warspite,* completed 1884, was the last British Naval ship fitted with sail. *Orlando* Class armored cruisers, laid down 1875, were the first British cruisers fitted with triple-expansion engines. The Protected Cruisers, *Powerful* and *Terrible,* laid down in 1894, were the first large British warships fitted with water-tube boilers. The Light Cruiser, *Amethyst,* completed in 1904, was the first British cruiser fitted with turbine machinery.

The Light Cruiser, *Arethusa,* laid down in 1912, was the first British cruiser to burn oil fuel only, and was the ship on which high tensile protective steel was first fitted to contribute to structural strength. The Light Cruiser, *Champion,* built during World War I, was the first cruiser fitted with geared turbines. During World War I, Light Cruisers became larger, and more heavily armed. The special large Light Cruisers, *Courageous, Glorious,* and *Furious* were built. They were 786 feet long, displaced 18,000 tons, and had a speed of 32 knots. *Courageous* and *Glorious* mounted 4-15″ guns in twin turrents. *Furious* mounted a single 18″ gun in a turrent aft. She also had a hanger and a flying-off platform forward.

The Washington Treaty of 1922, and later treaties, imposed several limits on cruiser design. As we are all generally familiar with the resulting designs, no comment is given herein concerning them.

The Author concludes his discussion of cruisers by saying that the history of cruisers extends over the whole of the Royal Institution of Naval Architect's existence, and perhaps is wholly contained in this period, as *Tiger* Class, now being placed in service, may well be the last cruisers built for the Royal Navy. He states that the function of the cruiser has largely been usurped by the aircraft carrier, and to a lesser extent by other ships. If the cruiser re-emerges, he considers that it will almost certainly be as a guided missile firing ship.

Following the take-offs and landings of Ensign Ely on USS *Birmingham* in 1910, and USS *Pennsylvania* in 1911, the British Navy experimented with airplanes. Two seaplanes were carried on the Cruiser, *Hermes,* in 1913, one with folding wings. By 1915, a merchant ship had been converted to the Seaplane Carrier, *Ark Royal,* and two other conversions followed. By the middle of World War I, experience had shown the superiority of wheeled aircraft over seaplanes, and that Aircraft Carriers must be larger and faster. The conversion of the large Light Cruiser *Furious* into an Aircraft Carrier was authorized in 1917, thus becoming the forerunner of the modern Aircraft Carrier.

*Hermes,* started in 1917 and completed in 1924, was the first British aircraft carrier designed as such. During about this same period, the Chilean battleship *Admirante Cochrane* was purchased while building, and completed as the aircraft carrier *Eagle.* Their most powerful aircraft carriers during the early years after World War I, were the conversions of the other two large Light Cruisers, *Courageous* being completed in 1928 and *Glorious* in 1930.

*Illustrious* Class of three ships, completed in 1940, were the first ships to have armored flight decks and hangor sides, a feature that was of great value in World War II.

The Author brings his discussion up-to-date, describing the various new ships, conversions and modernizations. Mention is made of their development of the steam catapult and the angled flight deck. His discussion of aircraft carriers is concluded with statement that this type of ship has evolved during the half of the period under review, through a period of courageous development, but without its full potential being realized until World War II. There was much opinion before this war that aircraft carriers would prove to be too vulnerable to be of great value. The indispensable value of this type ship was proved during World War II, and it has finally displaced the battleship as the major capital ship of the fleet. In closing, the Author refers to "the remarkable post-war *Forrestal* Class of the United States Navy, and particularly to the United States nuclear driven carrier *Enterprise* at present under construction."

The evolution of the Torpedo Boat, Torpedo Gunboats, and Torpedo Boat Destroyers is traced from the development of the Whitehead automobile Torpedo in 1871, and the building of the light construction river launch, *Miranda,* having a speed of 16.4 knots. At first, torpedoes were towed, and the Torpedo Boat stopped to launch it. In 1877 HMS *Lightning* of 18.5 knots speed was fitted with 1-14″ single revolving torpedo tube. The torpedo had a range of 600 yards. The first Torpedo Gunboat in the British Navy was *Rattlesnake* of 19 knots, having 4-14″ torpedo tubes, 1-4″ gun and 6-3 pounders, completed in 1886.

Although these ships increased in size, they were not suitable for use at sea, and were superceded by the development of the Torpedo-boat Destroyer—now abbreviated to "Destroyer." The first British ship of this type was *Havock* of 26 knots, with 3-18″ torpedo tubes, 1-12 pounder, and 3-6 pounder guns. The highest speed attainable with reciprocating engines was about 31 knots. *Viper* was completed in 1899 with turbine drive giving a speed of 34 knots. The loss of *Cobra* in a storm, and reports of heavy weather damage from other destroyers, led to greater emphasis upon strength, sea-

worthiness, and habitability, leading to increased freeboard and high forecastles.

The pattern of Destroyer design had by this time become essentially fixed, and the Author continues its evolution to the present designs, and the rather late development of Corvettes and Frigates is traced. The Author concludes by stating "the destroyer, with its counterparts, the frigate and corvette, has played a most important part in the history of the Royal Navy during the century under review. During the latter half of the period, these vessels have played a vital part in safeguarding this country against two severe submarine attacks. The destroyer and the frigate today have never been more important to the Navy. They have become vital for defense against air and underwater attack and have taken on a variety of other duties to make them maids-of-all-work."

The Author starts his account of submarines with Confederate semi-submergable vessel *David* and its successful attack on the Federal ship *Housatonic*. As the Whitehead automobile torpedo had not been developed, a spar torpedo was used. The Author lists as being needed for the making of a successful submarine a steel hull, the Diesel engine, the storage battery, the periscope, and the torpedo (Whitehead, ed.).

Although Sir William White gave close study to some submarine designs late in the nineteenth century, no British submarines were ordered until shortly after the successful development of *Holland* in the United States. Starting in 1901, with small vessels having petrol engines, and slow speed, there was rapid progress to the steam turbine driven K Class with a surface speed of 24 knots (1915-17), a surface displacement of 1883 tons, 8-18″ torpedo tubes, 1-4″ gun and 1-3″ gun. One ship of the M Class (1917-18), 1600 tons surface displacement, was remarkable in that it mounted 1-12″ gun in addition to 4-18″ torpedo tubes and 1-3″ gun. Another M Class ship was fitted with a seaplane hangar. The R Class (1917-18) contained many features of current designs, such as strong anti-submarine qualities, and surface qualities subordinate to submerged qualities. Good streamlining, small appendage resistance, a single screw, and a powerful electric motor gave a submerged 15 knots, with a surface speed of 9.5 knots.

A further attempt to produce a fully effective fleet submarine without using steam resulted in XI, completed in 1925. Surface displacement and speed were 2780 tons and 19½ knots respectively. She carried 4-5.2″ guns in two turrets, and 6-21″ torpedo tubes. The *Severn* (River) Class (1933-35) had the high surface speed of 22.25 knots, with a submerged speed of 10 knots. There was but 1-4″ gun, but the six torpedo tubes were increased to 25″ diameter. Following German experience in World War II, two submarines, *Explorer* and *Excalibur* were built having turbine drive, the fuel being highly concentrated hydrogen peroxide in association with Diesel oil. Their speed exceeds twenty-five knots submerged.

The Author closes the section on submarines by saying that the most outstanding development in submarine design is the recent use of nuclear fuel for propulsion, and that the performance of the U.S. Navy in this field has been spectacular. The Author states, "The advent of this type vessel has produced the long hoped for true submarine and has heralded a new era in submarine tactics and capabilities. The period under review closes with the Royal Navy—in closest cooperation with the U.S. Navy—building the new nuclear propelled submarine *Dreadnought*, which will surely have as great an impact on naval thought as the *Dreadnought* of 1905."

Proposals for a system of minesweeping had been worked out before World War I. With the advent of war, the need for Minesweepers was acute, and several types of vessels were built and converted for this service. Minesweeper design continued to develop between World Wars I and II. World War II brought with it the need to cope with magnetic, acoustic, and pressure mines. World War II Minesweepers were of steel, which required degaussing. Since World War II, two classes of non-magnetic ships have been developed. The larger, *Coniston* Class, are composite built having aluminum alloy framing and double mahogany hull. The smaller ships are of the *Ham* and *Ley* Classes. The earlier ships of these classes were composite built, but the later ships are of all-wood construction.

The Author closes this portion of the paper with brief outlines of the developments of Sloops, Gunboats, Patrol Boats, Coastal Forces Craft, Repair, Depot and Maintenance Ships, and Landing Ships and Craft. Since World War II the aim to produce convertible Motor Torpedo-Boats and Motor Gunboats has resulted in the production of the *Gay*, *Dark*, and *Brave* Classes. *Gay* with petrol engines has a speed of 43 knots; *Dark* with Deltic Diesel engines has a speed of 47 knots, and *Brave* with gas-turbine engines has a speed of over 50 knots.

The Author lists selected technical developments, opening with a brief account of the Experiment Tanks at Torquay and Haslar, and both Froudes' pioneering achievements. The constantly increasing scope and facilities of tank-testing are outlined. A discussion of the advances in structural design follows. The past one hundred years have seen the gradual evolution of warship structural design from an art based largely on precedent and experience into a more scientific procedure embracing structural theory and experiment. The Beam Theory of hull design gradually gained accceptance, and was confirmed by Sir John Biles' classic experiments on the Torpedo Boat Destroyer, HMS *Wolf* (1903).

The close of the nineteenth century saw the

passing of the ram bow, the fitting of torpedo protection and hardened armor, the first full scale tests of side protective systems and tests to learn the variation of damage with distance from the explosion. Explosion tests were continued, and led to the fitting of bulges or blisters during and after World War I. These tests also revealed the adverse effect of structural discontinuities on resistance to explosive attack.

Early in the twentieth century, important advances in structural theory occurred. The Beam Theory was applied to component parts, as well as the hull as a whole. The behavior of plating under lateral pressure was studied. Tests were made to learn the actual compressive strengths of typical deck panels, as instability had been recognized as a limiting factor for structures under compression. The design of transvere framing of surface ships was advanced by the development of a way to analyze the stresses in frame rings. This method was of great importance when applied to submarine hulls.

After World War I, Treaty limitations demanded weight reduction wherever practicable. In addition to efforts to make more effective use of steel, and the use of the new "D" and "D-1" steels having about 44 percent more strength than medium steel, and "DW" (welding quality of slightly less strength), aluminum alloys were used where practicable to reduce weight. The use of electric welding also reduced weight.

Unexpectedly severe damage from underwater explosions focused attention on the problem of underwater protection, and on the prevention of shock damage to machinery and equipment. The Naval Construction Research Establishment was set up primarily to study this problem, and subsequent research there has produced major improvements in the shock protection of machinery, and in the design of hull structure.

Under "Materials," the Author discusses the materials used in the past century. Although *Birkenhead* and *Trident,* 6-gun paddle Frigates, completed in 1846, were the first iron warships built for the Royal Navy, *Warrior,* the first armor-clad warship entirely of iron was not launched until 1860. The French took the lead in using mild steel in lieu of iron in *Redoutable* in 1873. The first steel, of the Bessemer process, was unreliable, however, and reliable open-hearth steel of the Siemens-Martin process became available. Mild steel was first used in the Royal Navy in the cruisers *Iris* and *Mercury* (1875-77) and in the battleships *Colossus* and *Edinburgh* (designed 1878). After using iron rivets in steel hulls for a few years, the use of steel rivets became standard practice. Mild steel gradually replaced iron as hull material during 1880-90, and the question of iron versus mild steel changed to mild steel versus high tensile steel. Although mild steel remained the basic hull material, high strength steel was used for certain highly stressed portions of structure since early in the twentieth century.

As previously mentioned, the "D" group steels were developed after World War I. They were followed by "S" steel of somewhat lower strength, but superior where much working was needed. "S" steel was normalized or annealed. If unquenched, it was known as "SU."

These steels were, however, deficient in notch-toughness, and have been replaced recently by two new steels with guaranteed notch toughness. "A" steel is somewhat stronger than mild steel, and has replaced it for important structure one-half inch thick and over. "B" steel has replaced "DW" and "S" steels in all thickness, although it is slightly weaker. Where higher strengths are needed, satisfactory low alloy steels fully quenched and tempered have been developed.

Aluminum has been used for minor parts for some years. Recently, however, it has been used for the main structure of small vessels, such as minesweepers.

The Author outlines the development of the means of fastening the various parts of a ship to each other, giving most attention to electric welding. *Seagull* was the first all-welded vessel for the British fleet. *Leda,* a similar minesweeper of riveted construction, was built to furnish a direct comparison. Both were commissioned in 1938, and after extensive trials and analysis of design and building experience, it was concluded that the advantage lay with the all-welded ship, particularly in weight and cost. The general development of electric welding since then is so well known that it is not included in this account.

Regarding armament, guns used during the Crimean War (1854-57) were essentially the same design as those used against the Armada, excepting for size. All guns were cast in one piece, had smooth bores, the small ones being of bronze and the larger ones being of cast iron. Elongated projectiles and rifled guns were being developed by 1860. The first rifled guns used in the Royal Navy were breech loaders made by shrinking several layers of wrought iron over the rifled core. Lead coated projectiles were used. The breech mechanism was unsatisfactory, however, and there was a temporary return to muzzle loading guns in 1865. With improved breech mechanism, breech-loading guns were again adopted. The wire-wound gun was adopted in 1890, and its use continued until the late 1920's. Starting in 1923, tests were made between wire-wound and "all-steel" guns of various sizes from 4.7′ to 12″, which led to the adoption of the "all-steel" design.

Naval guns were generally mounted on wooden carriages, the recoil being taken by rope purchases, until about 1880, when the hydraulic buffer was introduced. Turrets were being developed at about this time, and were first fitted in the British Navy on *Monarch* (1869) and *Captain* (1869). Fire con-

trol, as we know it, did not exist until just before World War I, when a simple system was fitted.

The Author considers that the improved performance of jet engined aircraft has removed the last possibility of making the gun and its control mechanism an adequate defense weapon. The Royal Navy has developed short range and medium range guided missiles for defense against jet engined aircraft. The author states that outstanding progress in this field has been made in the United States Navy.

Until 1936, torpedo tubes were fitted to all surface ships of the Royal Navy from Destroyers to Battleships. An effective technique for launching torpedoes from aircraft eliminated the need for launching torpedoes from ships larger than Destroyers.

The serious submarine menace of World War I caused the development of the hydrophone for giving the direction of the submarine from the attacking vessel (but not the distance), and the depth charge for destroying it. Later, the ASDIC was developed. During World War II, ahead-throwing weapons such as "Hedgehog" and "Squid" were developed. Later, such new weapons as A/S mortars and all-around training and homing torpedoes have been developed.

A century ago, sails were the dominant means of propelling warships. There were several steam driven ships with paddlewheels in the Royal Navy. The screw propeller was being developed, and the screw tug *Rattler* had won a tug-of-war against the paddlewheel Tug *Alecto,* and there was some hope that steam-propelled ships could be built without the loss of broadside which paddlewheels entailed.

The slow engine speeds of 20-30 RPM a century ago required *increasing* gears to get suitable propeller speeds. HMS *Warrior* (1859-61) had a simple 2-cylinder horizontal trunk engine with jet condenser, driving the propeller shaft at 54 RPM and developing 5,500 IHP with 20 psi steam. Compound and triple expansion engines were developed, and boiler pressures rose to 300 psi by the end of the nineteenth century. Indicated horsepower had risen to 15,000 a shaft, and RPM to 120. As early as 1874, steam was being used to drive fans, pumps, capstans, steering engines, and hydraulic pumps, in addition to the main engines. By the 1890's, conditions had become favorable for the fitting of watertube boilers, and their use increased.

Mention has been made herein of the fitting of steam turbines to HMS *Viper,* which made a speed of over 34 knots on trial. With a steam pressure of 175 psi, a total of 10,000 SHP was developed at 1050 RPM. HMS *Dreadnought* had six ahead direct driven turbines (and four astern) developing a total of 23,000 SHP at 235 psi steam. The need for *reduction* gearing between the turbines and the propeller was realized, and gears were fitted to the H.P. turbines only in the Destroyers *Beaver* and *Badger* (1911); all turbines being so fitted two years later.

Following World War I, steam conditions rose from 235 psi saturated in 1918 to 400 psi and 700° F by 1939.

The advances made in two decades are clearly shown by the re-engining of *Queen Elizabeth* in 1938. The 24-1916 boilers providing 235 psi saturated steam were replaced by 8-boilers providing 400 psi steam at 700° F. The direct drive turbines of 75,000 SHP were replaced by geared turbines of 80,000 SHP. The savings in weight, space, and fuel consumption were considerable, and permitted military qualities to be much enhanced.

Experience in World War II and a complete review of the whole field have resulted in considerable advances in machinery design in the Royal Navy. *Daring* (1945-52) Class Destroyers was designed with steam at 850° F, and other improvements, including double reduction gears. This machinery was based on Destroyer machinery in the U.S. Navy.

Diesel engines are no longer confined to submarines and small vessels. As a result of World War II experience, emergency Diesel engines have been fitted to all major ships, and have replaced petrol engines in ship's boats. The Deltic Diesel engine replaced petrol engines in fast Patrol Boats in 1950. The development of the gas turbine has been such as to justify it being fitted as the main engines on the *Bold* and *Brave* Classes of fast Patrol Boats.

Gas turbines have also been fitted to Frigates of the *Tribal* Class, and to the new Guided Missile Destroyers to boost the output of the steam turbine plant. They have also been fitted to supplement the steam driven generators.

The Author closes his section on Marine Engineering by stating, "The period under review closes with the advent of nuclear propulsion with all the advantages it can offer and yet with all the problems it entails. The performance of nuclear propulsion on ships of the United States Navy has been most impressive. Apart from the several nuclear submarines in the United States Fleet, there are also building a nuclear aircraft carrier, and a nuclear driven frigate. In the Royal Navy the nuclear Submarine *Dreadnought*—using American produced machinery—is well progressed and the second (wholly British) nuclear Submarine has been authorized.

When the history of the second centenary of this Institution's existence comes to be written, these developments may seem to be even greater in their effect than the sweeping technical changes at its inception.

The use of electricity in the Royal Navy started in the early 1870's when batteries were fitted for firing guns. A ship was fitted with a dynamo in 1875

for the operation of searchlights. In 1881, *Inflexible* was fitted with electric lighting and searchlights supplied from an 800 volt D.C. Generator. Due to a fatal accident, voltage was reduced to 80. During the 1880's the larger ships were each fitted with 3-60 KW generators. By the end of the nineteenth century, electricity was used to drive ventilating fans, auxiliary machinery, and armament. The amount of current needed increased with the advent of wireless telegraph and as remote armament control developed. Current of 220 volts D.C. became standard on large ships in 1905, and generally 110 volts for small ships. The ring main distribution system was introduced in the cruiser *Defense* in 1905. The large and rapid increase in the amount of electric current needed in modern warships is so well known that it will not be included in this account. The overall increase in electrical capacities can be summarized about as follows: Battleships—1914-1946—five times; Carriers —1930-1955—four to five times; Cruisers—1910-1959—ten times; Destroyers—1916-1950—twenty-five times.

Following World War II, the electrical current was changed to 440 volts A.C. for new ships the size of destroyers and larger. Cables were generally lead sheathed until 1939-1945. They have since been sheathed with, first polychloroprene, and later by silicone rubber.

Flag signalling was the main means of passing messages in 1860, and remains an important method of tactical signalling. Flares, rockets, and the firing of guns were also used. Orders aboard ship were by pipe, bugle calls, speaking trumpet, and messenger. In the 1890's, flashing lights and searchlights were passing messages by Morse Code. Masthead semaphores were used from 1895 to 1906. Bridge semaphores were also fitted, and remained on small ships until 1938. Voice tubes and elementary type telephones were being used aboard ship in the 1890's.

Marconi demonstrated his wireless telegraph on several ships during maneuvers in 1899, ranges of 60-70 miles being achieved. By 1909, most of the larger ships had wireless equipment that could send and receive messages at ranges of 300-500 miles. Destroyers were being so fitted in 1910, and Submarines in 1912. Naval seaplanes were also fitted with transmitters at this time. Thus, warships of all classes were fitted with satisfactory wireless equipment at the outbreak of World War I. Continual development has occurred since, including such notable advances as the pneumatic sending of messages, voice messages between ships and aircraft, and the sending and receiving of messages by automatic teletyping.

Radar was first fitted in HMS *Sheffield* in 1938, giving long range air warnings. A few ships were so fitted the following year; just before the outbreak of war. Aircraft direction using radar information was developed in the Royal Navy by 1940, when there were a number of successful interceptions. Early plotting arrangements were elementary, and directions were sent by wireless telegraph until voice equipment became available. An urgent need for protection against dive bombers resulted in the fitting of close-range fire control radar in 1940. Radar for detecting ships rather than aircraft were fitted, starting in 1941.

The contribution of radar to the efficiency of the Royal Navy during World War II can not be overstated, according to the Author. Progress has continued, until now a single set gives range, bearing, and height information, and also long range detection. Radar is also used to direct guided missiles to the target.

The use of armor for warship protection falls almost wholly within the period covered by this Paper. Iron armor was used to protect floating batteries during the Crimean War. (1854-57). The French ship *La Gloire*, having 4¾" iron armor, was completed in 1858. HMS *Warrior* (1859-61) had 4½" armor. As guns became more destructive, armor increased until 2-12" thicknesses of iron were fitted to *Inflexible* (1881). Steel was not viewed favorably, as steel quality was uncertain at that time. A compromise was developed in which a steel face one-third of the total thickness was welded to an iron back, this ratio having been found best. This compound armor was found to be as effective as iron armor 50 percent thicker, and was used on all ships of the Royal Navy between 1881 and 1890. The greatest thickness of compound armor on British ships was 20", tapering to 16", on *Nile* (1888) and *Trafalgar* (1887).

Improved steel led to the use of solid steel armor for secondary protection in 1891, while compound armor was used for the main protection. During the 1890's, Harvey, in the United States, developed a superior steel armor, having a hard face, but the back was lacking in toughness. None the less, 9" of Harvey armor was considered adequate for *Majestic* Class (1895-97). A little later, Krupp's in Germany further improved armor by using nickel chrome alloy steel and a new differential treatment during hardening. These processes produced what is known as "cemented" armor, which was used for thicknesses of 3" and over.

At first, armor was fitted throughout the length of the ship, tapering in thickness beyond the guns and magazines. Gun elevation angles were low at first, resulting in great thickness in the side belt, deck armor being relatively thin, to serve mainly as splinter protection. First, the high angle gun fire developed by World War I, then the increased danger from aircraft bombs, caused a major increase in the thickness of deck armor. The heaviest armor fitted in the British Navy in the later part of the century under review was 16" cemented side armor, and 6½" non-cemented deck armor. Due to armor's great weight, efforts to reduce this weight

resulted in omitting armor at the ends, creating a citadel in the central part of the ship, protecting vital areas with the greatest practicable armor thickness.

A century ago, the wooden warships were ventilated by wind sails, screens, and in good weather, by the open gun ports. Following this period, ventilator cowls were fitted. As ships had but meager subdivision in this period, the flow of air to the boiler furnaces provided a most valuable increase in ventilation. As subdivision increased, trunks were fitted to the cowls, to lead the air to the various compartments.

The steam fan was introduced about 1867. By the end of the nineteenth century they were being electrically driven, resulting in less noise, but little wild heat, and occupying less space. These fans were of the propeller or centrifugal type—more recently many have been of the screw or axial-flow type. Steam heaters were added to ventilation systems in 1903. The rate of air change for compartments was specified in 1938, and was generally satisfactory for pre-war ships. With the increased complements, and much added heat-producing equipment, such as electronic gear, and ships being at General Quarters for long periods, this simple method of designing ventilation systems no longer sufficed. Ventilation systems are now designed on the basis of air-borne removal of the total heat dissipated in a compartment, including solar radiation on boundary structure, heat from adjacent hot spaces, and heat transfer from personnel, equipment, etc.

Full air conditioning, controlling temperature and moisture content, air motion, purification, and cleaning provides the only means of maintaining top efficiency under all conditions in modern ships. Weight, space, and cost have prevented extensive fitting of full air-conditioning in existing ships. Generally, living and working spaces have normal ventilation only, air-conditioning (cooling) being confined to vital action stations, and a few special spaces, such as sick bays. New design ships will, however, have extensive air-conditioning.

There has been a steady improvement in warship accommodation standards in the past century, involving a continuing struggle to achieve within the space and conditions obtaining. Accommodations were very simple and rugged a century ago. The advent of steam and steel permitted marked advances. Steam made power available for fans, evaporators, electric lighting, auxiliary machinery, and heating. This, with iron construction, ended the damp interiors common to wooden ships, which led to high sickness rates amongst crews.

Galleys developed from the mid-nineteenth century solid fuel firehearths to crude-oil firehearths with oil heater pressure system of World War I and the steady flow Diesel oil burner of World War II. Washing facilities changed from buckets on the mess deck in the old sailing ships to hinged wash basins and hot and cold showers of ships in World War II.

Evaporators considerably increased the amount of potable water available, and nearly eliminated dysentery. The fitting of cold storage for food preservation added considerably to the health and comfort of the crew. The adding of much equipment, and of men to maintain and man it, during World War II, caused a general lowering of habitability standards.

Habitability conditions have again received very detailed attention since World War II. Marked food improvement has resulted from removal of all preparation and eating of food from the messdecks to centralized dining halls, food preparation spaces, services, etc. The resulting reduction in messdeck areas has been compensated by the increased use of tiered bunks instead of hammocks and attention of optimum layout, better fittings, and recreational facilities.

This paper includes outline drawings of the various types of ships in the Royal Navy throughout the past century.

The author closes by acknowledging the considerable help he received from various sources while writing the paper.

Although the Author describes the outstanding ships of the British Navy for the past century, I fail to find mention of a very famous British Warship—one famous long before HMS *Dreadnought* (1905-06). I refer to HMS *Pinafore* (1878)!

*Editor's Note: A condensation of the second paper which was presented at the meeting will be carried in the next issue of the* JOURNAL.

# *ADVENTURES IN ENERGY CONVERSION*

**ACKNOWLEDGMENT**

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THIS IS RIGHTLY called an adventurous age. The last great land mass of the world, Antarctica, is yielding to man's exploration. The depths of the oceans and the extremities of the atmosphere are being probed. Instruments are being designed for landings on the moon and nearby planets. The minds of scientists are pushing inward into the nucleus of the atom and outward to distant galaxies. As we explore, we learn. And as we learn, we have many opportunities to put this new knowledge to work for mankind and through speculative—adventurous—technological developments here on earth.

Among these speculative technological opportunities, some of the most interesting are those related to energy conversion, for the wresting of available energy in the form of electricity from the more primitive forms in which it has been stored away in the crust of the earth has long been a major challenge to the engineer. To date, the only economical large-scale method of obtaining electricity from the earth's crust has been to burn fossil fuels in a boiler and expand the resulting superheated steam through a turbine which rotates a powerful magnet inside some stationary coils of wire. (Figure 1) Associated with the process is the inherent thermodynamic inefficiency of the steam cycle, a measure of which is the waste heat that must inevitably be discharged into the condenser. When this and other losses are taken into account, a modern steam turbo-generator system is limited to an over-all efficiency of about 39 per cent. In other words, it re-

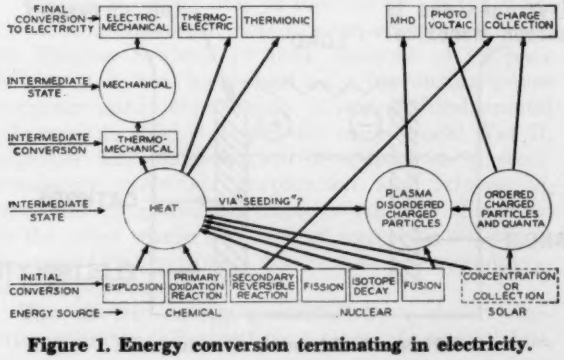



**Figure 1. Energy conversion terminating in electricity.**

quires about 8,700 Btu of fuel for each kw-hr of electricity produced.

We know of two ways to get around the thermodynamic limitation. One is to avoid it entirely by converting the stored chemical energy of the fuel directly into electric energy without the intermediate step of conversion into heat and mechanical energy (Figure 1). The other is to increase the temperature at which the chemical energy is converted into heat of working fluid. Much progress has been made in the design of turbines and in improving the materials from which they are constructed, leading to operation at higher and yet higher temperatures. More progress can be expected. However, there are signs that this "vein" may be "petering out." The more adventurous utilities and electrical manufacturers are beginning to "prospect" in other technological areas that offer opportunities to bypass the thermodynamic limitation, to make a really significant increase in temperature, or at least to simplify the system by elimination of rotating machinery (Figure 1).

What are some of these other areas that look promising, and what are the chances of finding "gold" therein?

## FUEL CELL

One of these areas, and from the thermodynamic point of view certainly the most attractive, is the fuel cell (Figure 2). It is not a new idea; in fact it is more than 100 years old. When it was originally conceived, the basic sciences of thermodynamics and electrochemistry were not yet strong enough to support the development of a practical device, and electrical engineering had not yet developed enough applications for electric energy to provide an adequate incentive. Later, in the first third of this century, the rapid development of the steam turbine and the internal combustion engine diverted attention from the fuel cell. Thus, it has only been during the past decade or two that scientists and engineers have returned to this old idea with renewed interest and determination to make it pay off. Many

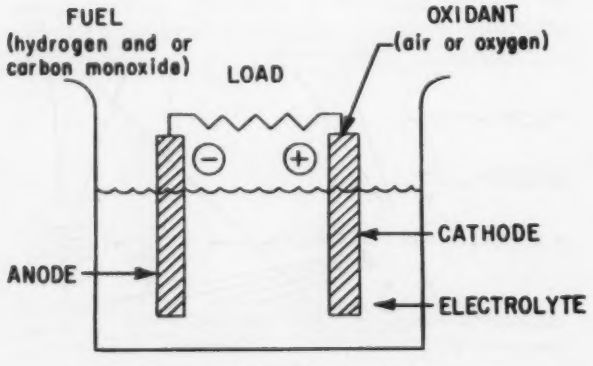



**Figure 2. Schematic of a fuel cell.**

alternatives, having widely different temperatures and pressures, reactants, electrolytes and catalysts, electrode configurations, and so on, are now being worked on. Some names given to these alternative combinations are Hydrox—essentially any low- or intermediate-temperature hydrogen-burning cell; Redox—a more complicated cell in which the reduction and oxidation reactions take place on intermediary substances which are then passed over inert electrodes where they release or absorb electrons; Molten Salt—a high temperature cell using molten salt, such as alkali carbonates, as electrolyte; Carbox—a high-temperature carbon-oxygen system; and of course there are many others.

One type of cell that has been given considerable attention at the General Electric Company is the ion-exchange membrane hydrox cell. Most of our experience has been with acid ion membrane cells (Figure 3), although basic ion cells are also feasible. Water is formed at the oxygen electrode as the

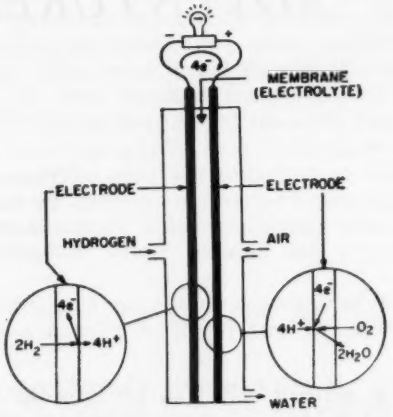



**Figure 3. Schematic of ion-membrane fuel cell.**

end product of the electrochemical reaction, as can be seen in the photograph of a small demonstrator cell (Figure 4). Inasmuch as this type of cell is rather compact and light in weight, operates at low temperature and pressure, and yet has reasonably high efficiency, it is suitable for military and other portable or mobile power supply applications, including those for certain types of space vehicles. Current density as high as 40 to 50 amperes per square foot of membrane can be obtained, and the power density can approach 25 watts per square foot (Figure 5). The specific fuel consumption varies from less than 0.08 pound of hydrogen per kw-hr at very light loads, to about 0.15 pound per kw-hr at maximum power density (Figure 6). These extremes are equivalent to about 4,900 Btu per kw-hr or 74 per cent efficiency and 9,200 Btu per kw-hr or 39 per cent efficiency, respectively. The tendency for efficiency to be highest at light load and to drop off with increasing load is charac-

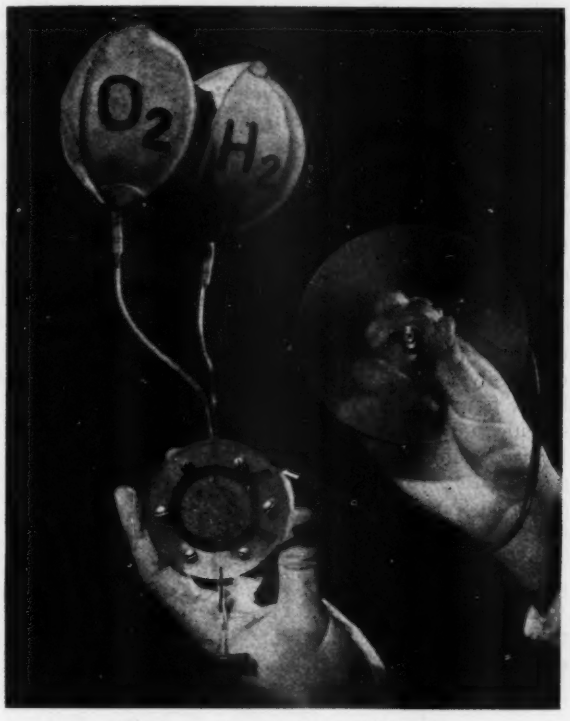



Figure 4. Ion-membrane fuel cell.

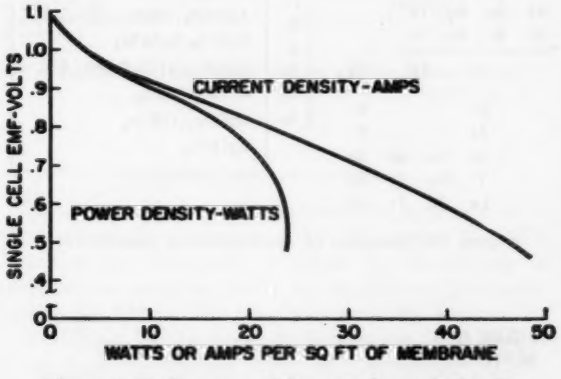



Figure 5. Performance of ion-membrane fuel cell.

teristic of fuel cells generally, although it varies considerably from one type of cell to another.

A quick survey of the present and the projected state of the art (Figure 7) indicates that such a cell might have a basic cost as low as $210 per kw-hr. An alkaline hydrox cell, which would avoid the use of platinoid catalyst material could conceivably bring this cost down; we project a basic cost as low as $42 per kw-hr. On the other hand, a molten carbonate cell which could "burn" less expensive fuel at very high efficiency might eventually have a cost on the order of $150 per kw-hr.

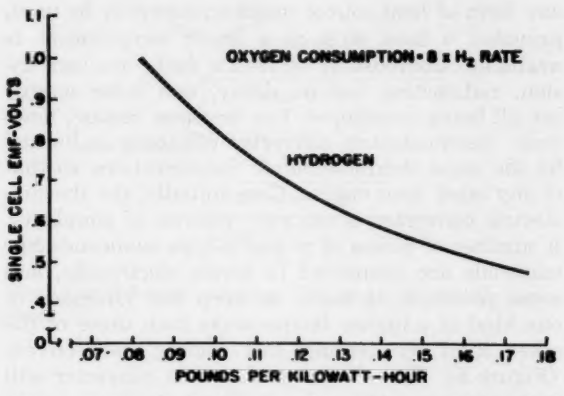



Figure 6. Specific fuel consumption of ion-membrane fuel cell.

| | EFFICIENCY | | | WATTS/FT³* | $/KW** (PRESENT PROJECTED RANGE) |
|---|---|---|---|---|---|
| | MAX OPEN CIRCUIT | | FULL LOAD | | |
| | EXPT. | THEORY | | | |
| CARBONACEOUS ACID AND ALKALINE | ? | 91% | STEEP $\Delta\epsilon$ | ? | $150 UP |
| MOLTEN SALT CARBONATE | 50-80% | 99% | FLAT $\Delta\epsilon$ | 100-1000 | $150 UP |
| HYDROX ACID ALKALINE | ≤80% | 83% | VARIES FROM FLAT TO STEEP $\Delta\epsilon$ | 150-1000 | $210 UP |
| LOW T | 80% | 83% | | 150-1000 | $42 UP |
| INT T | 80% | 83% | | TO 3000 | ? |

Figure 7. Known state of the fuel cell art. *Cell only. **Cell only, not installed.

There is a long way yet to go. The ion exchange membranes are expensive and difficult to manufacture and handle. Less costly catalysts must be found. Operating life must be extended—and this leads to some very challenging materials problems, especially with respect to the high-temperature cells. Full load efficiency needs to be improved. Control problems must be investigated for various applications. And, of course, designs must be worked out for easy, low-cost maintenance.

## THERMOELECTRIC CONVERSION

Almost as old an idea as the fuel cell is the thermoelectric converter, based on an effect first noted by Thomas Seebeck in 1821. Because of its poor efficiency it has been used only for measurement purposes until very recently. However, fundamental advances in solid-state physics since World War II, together with technological developments in semiconductor materials preparation and fabrication, have led to substantial improvements in efficiency, to the point where this type of converter must now be considered seriously for certain energy conversion applications.

The electric energy generated by a thermoelectric converter is derived from thermal energy; thus,

any form of heat source might conceivably be used, provided a heat sink at a lower temperature is available. Combustion of fossile fuels, nuclear fission, radioactive isotope decay, and solar energy are all being considered. For the same reason, however, thermoelectric converter efficiency is limited by the same thermodynamic considerations as that of any other heat engine. Conceptually, the thermoelectric converter is the very essence of simplicity. A number of pieces of p- and n-type semiconductor materials are connected in series electrically, and some provision is made to keep the junctions of one kind at a higher temperature than those of the other kind by heating and cooling, respectively (Figure 8). The efficiency of such a converter will

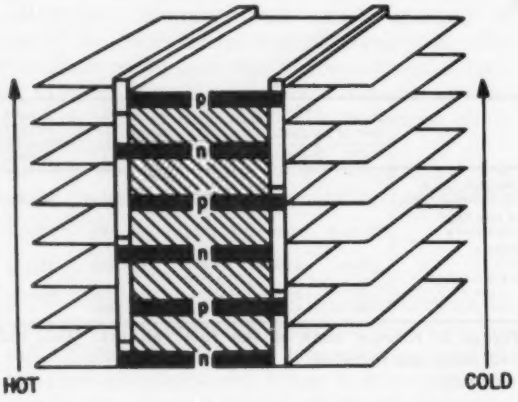



Figure 8. Schematic of a thermoelectric generator.

depend on the particular configuration used, which must be optimized for each application, and also on a figure of merit for the semiconductor materials employed (Figure 9). Of course it can never be higher than the ideal thermodynamic efficiency. $(T_1-T_2)/T_1$, for the source and sink temperatures available. The figure of merit is proportional to the Seebeck coefficient (volts per degree) squared, and inversely proportional to the electrical resistivity and the thermal conductivity (Figure 9).

$$Z = \frac{S^2}{\rho_K}$$

Z = Figure of merit

S = Seebeck coefficient

$\rho$ = Electrical resistivity

$\kappa$ = Thermal conductivity

Figure 9. Factors affecting the figure of merit.

A very large effort is currently being directed to the problem of increasing the figure of merit, or the temperature, or both. The number of possible materials to be studied is very large (Figure 10). Most of the groups of the periodic table have some interest. Binary, ternary, and even higher component systems of stoichiometric ratios as well as intermediate ones are at least potential candidates. Thus, although the job of selecting the best material is worse than looking for a needle in a haystack, the possibility that substantial improvement can be made is fairly good. The present status is indicated by Figure 11. Bismuth telluride has a figure of merit of more than 2, but is useful only at relatively low temperature. Lead telluride has a lower figure of merit at higher temperature. Cobalt silicide has a figure of merit of about 1 at nearly 1,000 C, and therefore offers the possibility of approximately 15 per cent efficiency. A ternary compound, copper gallium telluride, has a still higher figure of merit, but only slightly better efficiency. The challenge, of course, is to find a material with a figure of merit of approximately 3.0 at 1,000 C (1,832 F) or higher. Such a material could be used to make a converter having at least 30 per cent efficiency. We currently know of no such material,

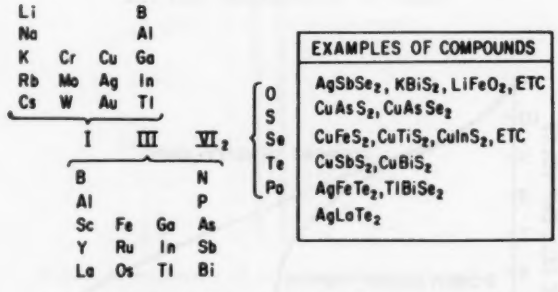



Figure 10. Examples of semiconductor compounds.

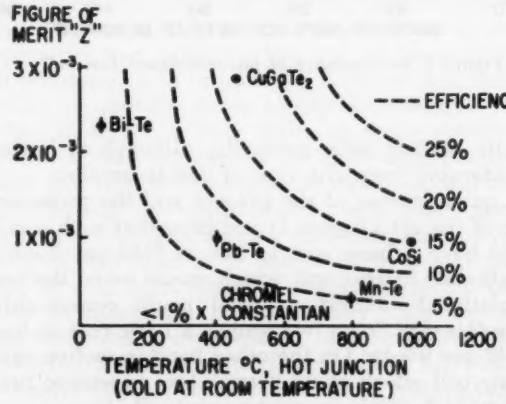



Figure 11. Examples of semiconductor properties.

nor can we be sure that one even exists. But it seems to be worth looking for.

Presently known thermoelectric materials, although not economically suitable for large-scale energy conversion, are adequate for certain specialty applications where the inherent simplicity of this method is attractive. Notable among these are the kerosene-operated radio developed by the Russians, and the low-power space power supplies, using radioactive isotopes, developed in this country. Aside from the semiconductor materials problem, there are also a number of systems problems involving optimum configuration, junction technology, controls, and so on, that merit competent attention (Figure 12).

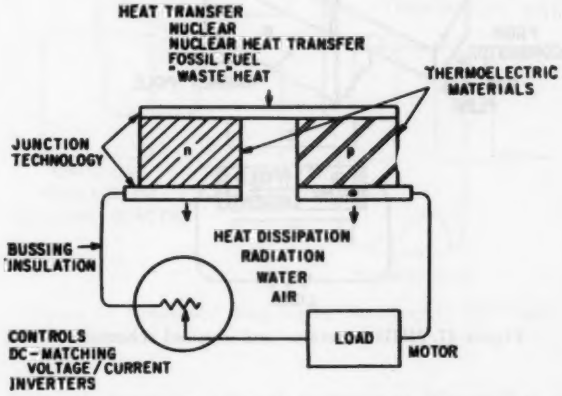



**Figure 12. Thermoelectric power system alternatives.**

## THERMIONIC CONVERSION

The use of thermionic emission to generate electricity was first proposed by Schlicter in 1915, Charlton and Langmuir studied the possibility of using a cesium-filled diode as an electric generator during the 1920's. The idea was recently revived by V. C. Wilson and a great deal of work is currently being done on various types of thermionic generators.

Again the basic idea is rather simple (Figure 13). Electrons are driven out of a heated cathode by thermal agitation and escape with sufficient energy to migrate to a nearby anode against a potential difference which includes an output voltage across a load. The energy levels involved are illustrated in Figure 14. In a high-vacuum diode, the electrons must also have sufficient energy to surmount the space charge barrier represented by path *b* in this diagram. The space charge can be minimized by making the cathode-anode spacing extremely small; however, this is difficult to do except in small converter sizes. Another way to overcome the space charge is to fill the space with enough slow-moving

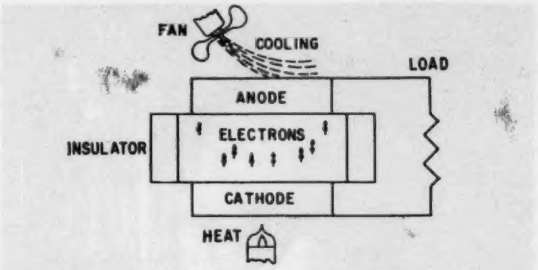



**Figure 13. Schematic diagram of a simple thermionic converter.**

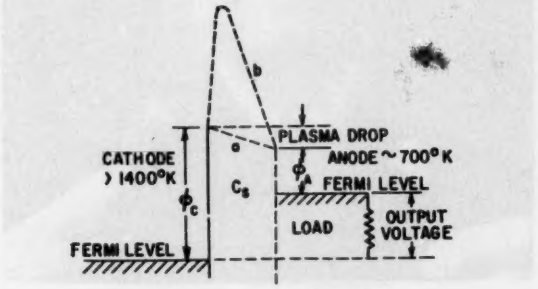



**Figure 14. Electron energy in a thermionic converter.**

positive ions to neutralize the field of the electrons. Cesium vapor has been used effectively for this purpose. Figure 15 shows a tiny vacuum converter button which is currently in production, and a typical laboratory-converter containing cesium.

If the emitter temperature is high enough, the cesium-filled thermionic converter currently operates at an efficiency comparable to that of the best thermoelectric converters (Figure 16). Because of its low weight, it should be used as a solar energy converter for space-power applications. It may also find application as a nuclear reactor topping unit. Preliminary tests indicate that thermionic converters need not be adversely affected by radiation, even if placed inside the reactor core, and that the neutron absorption of such converters can be kept acceptably low.

There are many imposing problems, however, before economically feasible devices can be designed and built. One is the ever present problem of long-life, high-current-density cathodes and low-work-function anodes. Another is the problem of thermal isolation of cathode from anode. Still others involve better methods of fabrication, especially of seals, to maintain accurate spacing and zero leakage. Before such converters can be used in reactors, a great deal more must be known about the long-term effects of radiation. Even the problem of testing full-scale solar thermionic converters for space use is a formidable one, for it requires a very large, well-collimated light source having the right spectral distri-

Figure 15. J. E. Beggs of the General Electric Research Laboratory displays laboratory models of a vacuum converter (left) and a cesium-filled gas converter (right).

| Type | Efficiency | Weight per unit of power | Emitter Temperature |
|---|---|---|---|
| Vacuum | 4½ % | 25 lb/kw | 1100 C |
| Gas-filled | 17% | 4 lb/kw | 1900 C |

Figure 16. Thermionic converter performance.

bution, in a vacuum environment, with provision for radiating waste energy to a surface approximating a black body at zero degrees Kelvin. There is plenty of opportunity for adventure here!

### MAGNETOHYDRODYNAMIC CONVERTERS

It is difficult to say which of many antecedents really represents the beginning of MHD (magnetohydrodynamic) energy conversion. Certainly Faraday had the germ of the idea which is currently being developed. However, it is probably safe to say that the background of plasma physics recently resulting from studies of the upper atmosphere, sun, and stars, and from work on nuclear fusion, as well as the technological advances resulting from ballistic missile nose-cone re-entry work have made it possible only in the last few years to consider seriously the development of such a device. Although by far the most speculative of all the ideas covered in this article, the MHD converter has so much potential merit that it cannot be ignored today.

Given a conducting compressible fluid (plasma), moving at high velocity, there are a number of possible ways to remove electric energy from it. The simplest method, on which most of the effort is focused today, is the old Faraday principle of a moving conductor in a magnetic field (Figure 17). In order to ionize air to an extent which will make

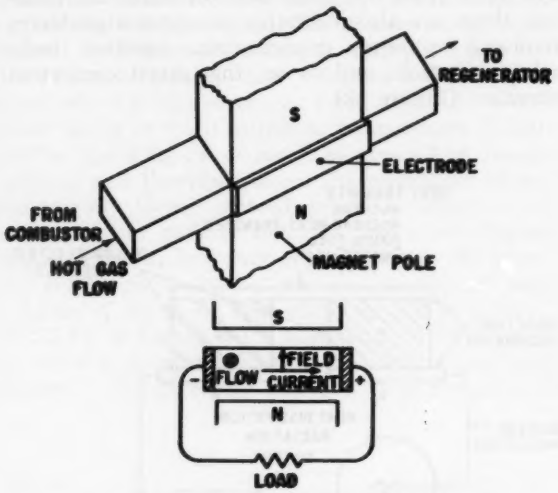



Figure 17. MHD generator and channel schematics.

it sufficiently conductive for this purpose, it must be heated to approximately 4,000 K (6,740 F). By "seeding" with an alkali metal vapor such as potassium, the temperature can be lowered to approximately 2,500 K (4,040 F), but this is still a lot hotter than engineers are accustomed to handle, except in the case of nose cones, rocket engines, and electric arcs, where the duration is very short. The easiest way to produce a suitable plasma in small quantity is to heat air or inert gas in an electric arc. Most experimenters begin in this way. In order to progress to larger-scale testing, however, it is necessary to devlop suitable combustion processes. Inasmuch as the required temperature cannot be reached by burning coal, oil, or gas with air at room temperature, the combustion air must be preheated at least 2,000 F, or nearly pure oxygen must be used instead of air.

Work is now in progress at General Electric and elsewhere on a MHD converter of 25 to 50 kw. Unlike the other energy converters described in this article, the MHD generator improves in efficiency as its size increases and would generally be used in sizes of 100,000 kw or more for economic electric power generation; therefore, any statement about the efficiency of these small experimental units would be meaningless. It is significant, however, that the behavior of these small units agrees

reasonably well with theory.

The thermodynamic cycle efficiency of an MHD converter alone is not very high because it must reject heat at a temperature determined by the minimum acceptable conductivity of the working fluid, which, as we have seen, is very high. Consequently the MHD converter is generally considered as a topping unit, used in conjunction with a high-temperature steam-turbine generator to increase over-

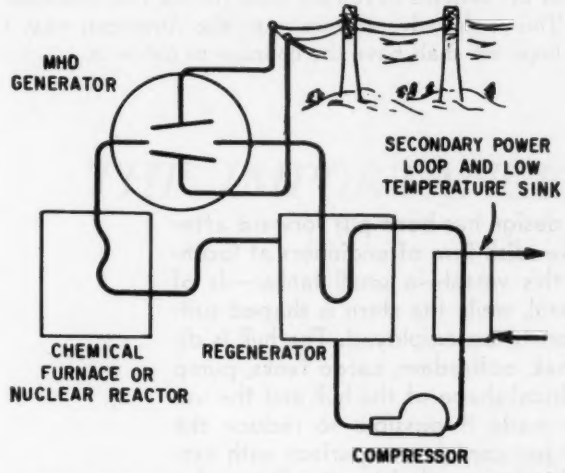



**Figure 18. Schematic diagram of closed-cycle MHD generator system.**

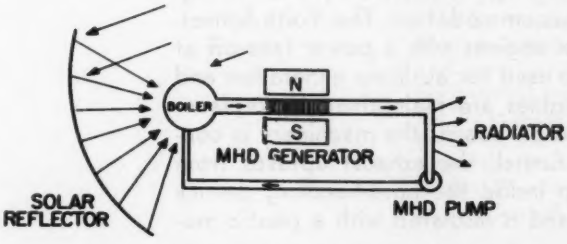



**Figure 19. Closed-cycle MHD generator for continuous operation in space.**

all plant efficiency. Cycle studies based on hypothetical designs of MHD generators lead to predicted values for reduction in heat rate ranging from 15 per cent to 30 per cent, or increases in over-all plant efficiency from around 40 per cent (today's best) to somewhere between 46 per cent and 52 per cent. Figure 18 is a conceptual diagram of a closed-loop MHD topping unit. An open-loop system would be similar, except that combustion would take place directly in the air before it goes into the MHD generator, outside air would be sucked into the compressor, and the exhaust would go up a stack after all possible heat had been wrung out of it by preheaters, boilers, and economizers.

There is no longer any doubt that an MHD converter will work—for a little while at least. The immediate engineering problems are concerned with learning how to make it work for thousands of hours without extended shutdown for repairs. The achievement of this goal will depend primarily on whether better materials can be found, or better ways can be found to use the materials we already have. Particularly challenging is the design of the electrodes, the heat exchanger, and the combustor for an open-loop system, especially if powdered coal is used as the fuel.

Figure 19 shows a closed-cycle MHD converter using a cesium boiler, heated and ionized by concentrated solar energy that may be attractive for space applications. Figure 20 indicates that a rocket engine in conjunction with an MHD converter could be used to generate large amounts of power in short bursts. Specialized applications of MHD such as this may be closer to realization than economic use in electric utility systems.

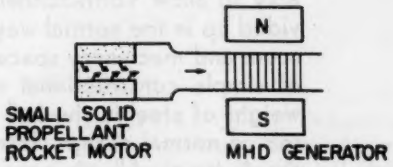



**Figure 20. Open-cycle MHD generator for short burst of electric power.**

## ORGANIZATION AND FINANCING

Thus it appears that all of the fields of energy conversion may be attractive to the prospector. There is ample evidence that valuable results may be achieved if only we look in the right places and dig deep enough. The only questions are "Who will put up the grub stake?" and "What kind of prospector is most likely to find pay dirt?"

This kind of prospecting is more like the search for oil that lies deep beneath the ground than like the search for gold and other metals in surface deposits. Large, well organized teams will be needed, including scientists and engineers of many different kinds. Especially important will be the materials specialists for, as we have seen, the limitations of existing materials are critical barriers in every line of development. Intelligent team leaders also are essential, for the work will be extremely expensive in any case, and unless it is properly co-ordinated it may be prohibitively expensive. The management of speculative projects such as this will require a rare combination of imaginative courage to strike out in unexplored directions, and technological judgment to know when to abandon an unproductive line of exploration.

The money question usually boils down to how

much Government support should be made available. It would be all too easy to point to other large speculative developments, such as atomic energy, and suggest that the Government pick up the check. Except in the case of certain specifically military energy conversion developments, we should not take this easy way out. The distinguishing feature of free societies, as opposed to Communist and other Socialist systems, is the dependence upon competitive private enterprise as the primary means of economic development. Not only is private enterprise more appropriate philosophically to a free society; it also produces better results, as history has shown, whenever it has been allowed to operate effectively. Instead of asking for Government support, therefore, or just sitting back and waiting for military projects to create the necessary technology for industrial and commercial use, managers of American industry must be willing and able to lay on the line the necessary support for projects such as those we have been discussing, with confidence that if successful, they will be able to retain enough of the benefits to reward them for the risk involved. This is the adventurous way—the American way. I hope we shall have the courage to follow it.

A project for a vessel of unusual hull design has been put forward after extensive research by Marinkonsult, a Swedish firm of engineers at Gothenburg. The main part of the hull of this vessel—a small tanker—is of cylindrical shape. The bow is conventional, while the stern is shaped suitably to allow Voith-Schneider propulsion to be employed. The hull is divided up in the normal way into fore peak, cofferdam, cargo tanks, pump room and machinery spaces. The cylindrical shape of the hull and the use of simple constructional elements has made it possible to reduce the weight of steel in the hull by about 40 per cent in comparison with vessels of normal design. Transverse stability is provided by stabilizers of a simple type, while the vessel has exceptionally large bilge keels and a centerline bulkhead in the cargo tanks.

Similar efforts have been made to simplify the machinery and the rigging of the vessel, and also the crew accommodation. The Voith-Schneider propeller is driven by geared diesel engines with a power take-off at the forward end. These engines are also used for auxiliary generation and for driving the pumps in port. The engines are maintained by replacement, and only one engineer is required on board: the machinery is controlled from the bridge. There is no funnel, the exhaust uptakes from diesel engines and boiler being led up inside the hose-handling derrick posts. The deckhouse is of light alloy, and is insulated with a plastic material.

The naval architect who produced the design is Mr. C. E. Hagerling, who has designed several vessels for special duties and was responsible for the design of the sulphuric acid carrier *Ceres* (*SW*, 7.9.60). He has drawn attention to the saving in cost which is possible with the design. For a tanker of 750 dwt with a speed of about 9 knots and a crew of eight the cost would be 1,200,000 kroner, while a conventional vessel of this size would cost about 1,000,000 kroner more than this. Other advantages claimed for the design include evenly spread stresses in the hull, safer passage through locks and in ice, faster clearing of seas breaking over the ship and easier stripping of tanks. The design has been approved by Lloyd's Register and by the Swedish Shipping Board.

—From THE SHIPPING WORLD
16 November 1960

ROCCO V. VITTUCCI

# THE IMPORTANCE OF STANDARDIZATION TO NATIONAL DEFENSE

**THE AUTHOR**

*after receiving the ME and MME Degrees from Cornell University, began his professional work in Heat-Power at the American Gas and Electric Company, New York City. For several years he taught Mechanical Engineering at the University of Texas, where he published a Mechanical Engineering laboratory manual. He has been with the Navy Department, Bureau of Ships, since 1941, except for three years with the Engineering Division of E. I. du-Pont de Nemours and Company. His early work in the Bureau was in the Heat Balance and Ship Trials Branch. Later he worked in Minesweeping, and more recently, in the Standardization Planning Branch. A registered professional engineer in the State of Delaware and in the District of Columbia, he is presently organizing a new Basic Engineering and Electrical Design group in the Bureau's Preliminary Design Branch. The following paper forms the basis of a speech which he presented on 28 March 1960 to the Annual Meeting of the twenty-six societies making up The Technical Societies Council of New Jersey.*

CAN A PLANE from a disabled British aircraft carrier land safely on a U. S. carrier?

Will an electron tube made in Holland work satisfactorily in a U. S. military radio set?

Is there any practical way to stem the rising cost of armament?

In the event of an emergency, can the U. S. forces operate effectively with the military forces of the several NATO nations?

Practical solutions to these and many other problems vital to National Defense are even this day being produced through the techniques of standardization.

## WHAT IS STANDARDIZATION?

Before getting too deeply into the subject at hand it might be well to make a quick review of the broad concept of standardization. It is disturbing to see how few people, even in high places, seem to recognize the true meaning and the full value of good standardization. The popular misconception, held mostly by women, that it means drab gray uniforms for all women, and nothing but black Ford cars on the road is still altogether too prevalent. Let's set the record straight. This is not standardization!

STANDARDIZATION is a management tool—a

technique for achieving ECONOMY and EFFECTIVENESS. It has been defined in many ways; let's examine a few. Standardization is:

". . . The making and using of standards".

". . . The organized process of obtaining solutions to common problems".

"It is the evolutionary movement toward a desired degree of uniformity (but not necessarily exact duplication)".

The immediate results of this standardization process usually appear in the form of standards and specifications.

A STANDARD is:

"An agreement by authority, custom or general consent to a rule or model to be followed". (ASA)

"A satisfactory solution to a repeated problem".

"A specification intended for repeated use".

Without going into the difference between standards and specifications, let's just say that both of these "standards documents" products are vehicles —means to an end in standardization activity. They specify what we want in terms of interchangeability features such as DIMENSIONS, FUNCTIONS, and QUALITY.

*Ultimate Objectives*

Like any other effort, standardization requires personnel, time and money, the investment of which can be justified only for good reason—and the reasons are good! The ultimate objectives of standardization can be summed up in two broad terms—GREATER ECONOMY and INCREASED EFFECTIVENESS.

By ECONOMY we mean saving money, conserving resources (such as material and production facilities)—but most important the saving of manpower and time. Proper use of standards presents good, ready-made answers to problems that have already been solved and leaves the mind free to work creatively on those which have not. In the military this means more and better equipment at lower unit cost. In Industry it is frequently expressed as greater profits.

For the military services the second objective—INCREASED EFFECTIVENESS—is even more important than the first. It means increased ability to perform their job whether our forces are operating alone or in combination with our allies. It means operational compatibility of miscellaneous military equipments. It means assured quality of components, reliability of weapons systems, immediate availability of repair parts. It precludes the old tragedy—"For want of a nail a shoe was lost; for want of a shoe the horse was lost"—until finally a kingdom was lost. Here the value of the benefits is not so easy to assess. Good standardization could make the difference between preserving our American way of life or of possible complete annihilation.

WHERE CAN WE BEST USE STANDARDIZATION—THE NATIONAL PICTURE IN PERSPECTIVE

Let's take a management approach to the national picture for fiscal year 1961 to see where standardization can do the greatest good. As a general principle greatest savings are possible where there is the greatest spending.

Looking at the federal budget distribution of expenditures by function (Figure 1) we see that 54 cents out of each tax dollar goes to national security. Note that this is more than the total of all individual income taxes, which provide only 52 cents of each budget dollar. Of a total federal budget of 79.8 billion dollars, we see that 45.6 billion dollars are used for national security (Figure 2). Of this amount the purchase of aircraft, missiles, ships and other military equipment gobbles up 13.6 billion, while costs of operation and maintenance of equipment and facilities takes another 10.3 billion (Figure 3). These areas are particularly susceptible to standardization. The civilian administration of this mammoth military complex requires the employment of 1,048,000 civilian personnel by the federal government, considerably more than that required for any other function (Figure 4). Certainly, of all the government functional areas, it appears that national security with its enormous expenditures

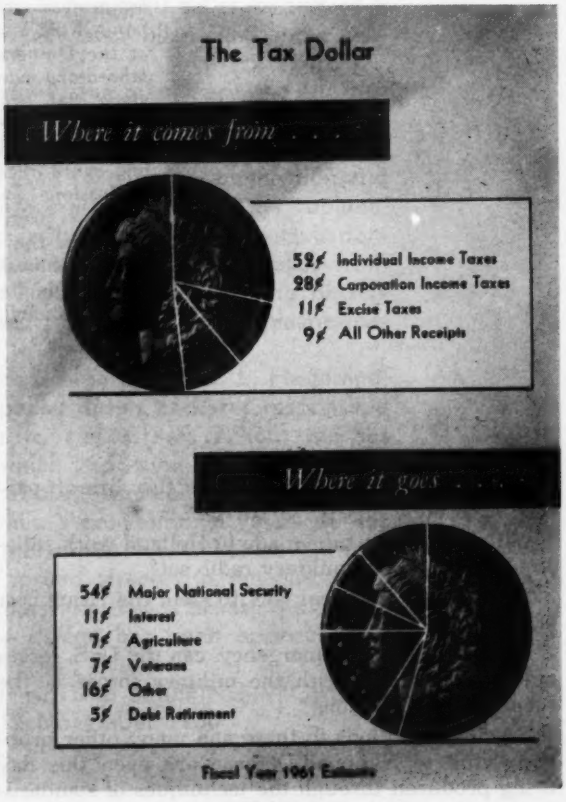



Figure 1

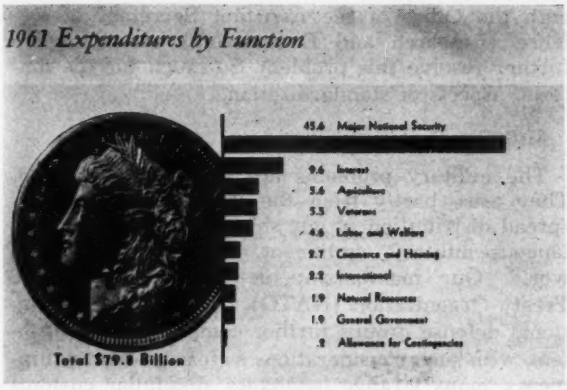



Figure 2

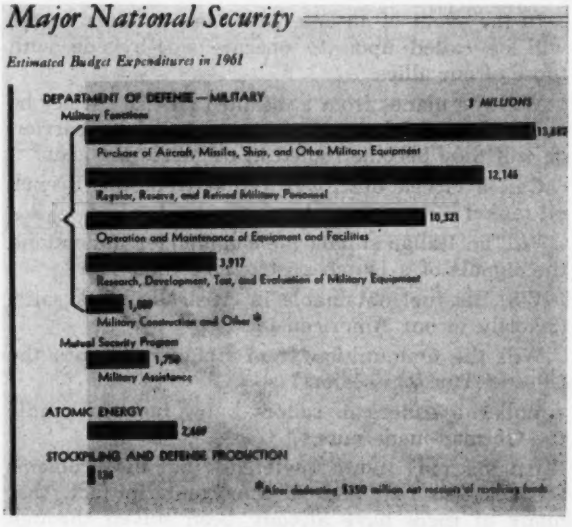



Figure 3

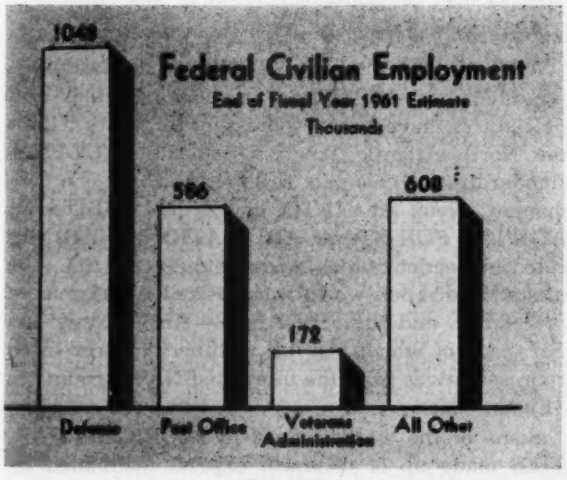



Figure 4

should be the most fertile area in which to seek standardization savings. Even a dainty 1 or 2 per cent saving here would overshadow the greatest practical savings in any of the other functional areas.

All this would be merely academic to you were it not for the fact that this money comes from taxes. In the Department of Commerce Building in Washington there is a census clock which keeps ticking the estimated total number of people in the United States. The indicator has just passed the 180 million mark. From this number we can figure that the direct cost of national security is approximately $255.00 for every man, woman and child. You know who pays!

### ENORMITY OF THE PROBLEM—WHY WE NEED STANDARDIZATION

A romantic notion of national defense might suggest atomic submarines, together with strategic missiles such as Atlas, Titan, Minuteman and Polaris. This is fine except for one thing. It seems to ignore the fact that the military system is an enormous organization of human beings stationed all over the world. These people require pork and beans, shoes and socks, washing machines, pots and pans, tools and typewriters, and many less glamorous things,—all these in addition to mountains of military supplies. Actually, the number of items furnished through the military supply system runs in the millions!

*A look at the military supply system.*

Many years have been spent unifying our military supply systems. At the moment our federal cataloging system lists over 3½ million separate and distinct items of supply. Each year, due to new needs or advances in technology, over ½ million new items enter the supply system. At the same time, a number of other items are eliminated from the supply system because they are obsolete or surplus. Despite the gigantic efforts of the standardization and cataloging programs, the total number of items in the system continues to show a net increase. Reports show that during the past year 136,000 more items were ADDED to the system than were ELIMINATED. It is hoped that better supply-management procedures will soon reverse this trend and ultimately bring about a net reduction in our monumental supply system.

*A major problem area—Drawings.*

The problem is not limited to items of supply. One of the most difficult problem areas is that of technical drawing management. Here are some rough figures. It has been estimated that for each million dollars that goes into the development of new items for the military, about $300,000 goes to engineering and drawings. Recent statements of the military expenditure for drawings alone were pegged at 1.5 billion dollars annually, and the cost of their reproduction an additional 1.2 billion. One source esti-

mated that the military files contain as many as 50 million drawings, that 6 million new and revised drawings were added each year, and that the number of prints for distribution and service approaches 1 billion. Certainly this is an area where the benefits of good standardization could be staggering.

Moreover, the study to simplify the area of drawing management and thereby to reduce costs, revealed that the military departments had been using 154 specifications and standards of some sort to specify engineering drawing requirements. Some of these were overlapping and conflicting. The recently issued Specification for Military Drawings, MIL-D-70327, was the answer to this dilemma. It is hoped that proper application of this new specification will remove the need for many of these conflicting specifications. The development of the first issue of the MilSpec for "Engineering Drawings and Associated Lists", MIL-D-80327, required the combined efforts of 22 military agencies and 10 Industry associations working for eight months. Direct costs for contracts were $250,000 and the manhours required exceeded 17,000. Despite this effort the document is still not completely satisfactory to all concerned and a revision is already underway.

Highlighted by the nationwide effort to standardize military drawing practices are the many related problems, such as methods of RAPID REPRODUCTION, TRANSMISSION and RETRIEVAL of engineering data. The engineering know-how on all the military standards in the world will be of little value unless this technical information can be made available to the designer on very short notice. This problem is presently receiving full attention of the military services. Included are studies of best means of utilizing microfilm, punch cards, aperature cards, etc. The military expects great gains in these areas.

*Some Other Problems.*

Many other areas of engineering standardization in the military cry for attention. Among these is the area of SIMULATED ENVIRONMENTAL TESTING of military equipment. Standardized test methods are needed to replace the many and varied tests now in existence. Also required are further development of RELIABILITY and QUALITY CONTROL techniques, as well as clear and more extensive portrayal of true environment. When these areas are further developed, it is hoped that simulated service testing in the laboratory will accurately predict the performance of equipment for the actual environmental conditions to which it will be exposed in service.

Another problem area—and this is general—is that of getting greater APPLICATION OF ENGINEERING KNOW-HOW into the standardization effort—and doing this particularly in the EARLIER STAGES of design, rather than waiting until the equipment is built. The Office of the Assistant Secretary of Defense (Supply and Logistics) is working with the Office of the Assistant Secretary of Defense (Research and Engineering) attempting to further resolve this problem. So much for the material aspects of standardization.

*Military Problems.*

The military problems are just as complicated. They arise partly from the sheer size and widespread distribution of our ships, planes and miscellaneous military equipment, located all over the world. Our membership in the North Atlantic Treaty Organization (NATO) and in other international defense groups further complicates the problem, with such considerations as foreign-built equipments, many strange languages, dissimilar customs and procedures—all of which must be brought into reasonable harmony for the mutual defense of these free nations.

In the event of an emergency our military forces will be called upon to operate side-by-side with those of our allies.

Will the planes from a disabled British carrier be able to land safely on a surviving American carrier, or will they become fouled in the arresting gear?

Can a Greek destroyer refuel from the French oil tanker?

Will an Italian submarine commander understand the signals of a Dutch destroyer commander?

Will the fuel obtainable in Australia work satisfactorily in our American jets?

Will the ammunition from Belgium fit into the rifles of Turkish soldiers?

Will the American sailors know how to handle the German-made mines?

All this may sound far-fetched but the problems are real—so real and so important, in fact, that many of them have already been solved through military standardization agreements.

## THE EXTENT OF STANDARDIZATION IN THE MILITARY

*Parts Emphasizing Military Aspects.*

Actually the military phases of standardization—those emphasizing military tactical doctrines and procedures, have been progressing for years within the North Atlantic Treaty Organization (NATO) standardization channels (Figure 5). There is a permanent group in NATO called the MILITARY AGENCY FOR STANDARDIZATION (MAS), located in London, which guides and records this type of standardization work. It consists of a chairman, a secretariat, and three BOARDS—Army, Navy and Air, each of which has full members or accredited representatives from the interested NATO countries (Figure 6).

Some of the work is done by WORKING PARTIES made up of technical experts nominated by participating countries or NATO operational com-

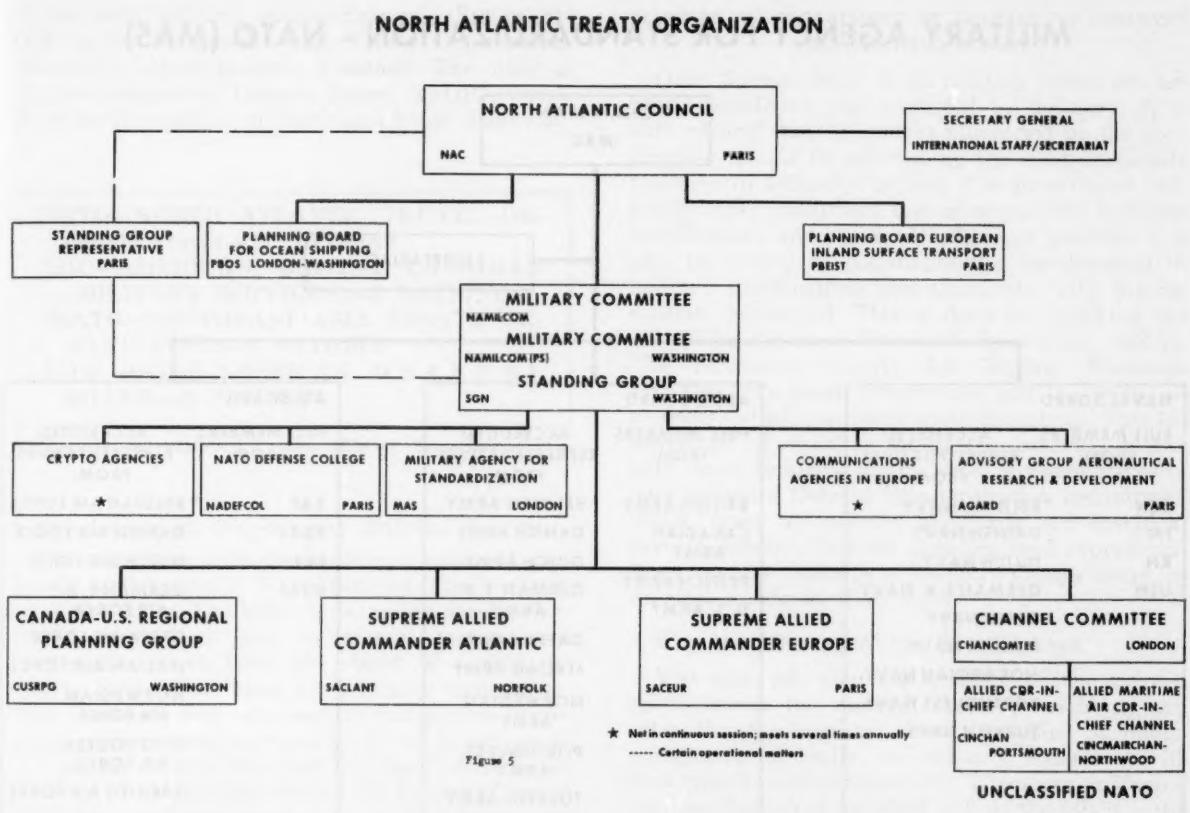



**Figure 5. North Atlantic Treaty Organization**

manders. Working parties meet at some convenient location to carry on the standardization work as a group. Since this involves travel costs and separation of the experts from their technical associates back home, there is a second, and possibly more common method of carrying on the standardization work. This is known as the CUSTODIAN/CORRESPONDENT method. One nation or operational command agrees to act as "Custodian" and then coordinates the efforts of all the other "Correspondent" nations as an agent of the MAS. The experts then carry out the work of technical coordination by mail up to the point of final agreement.

Regardless of which method is used, the results of NATO standardization work are recorded in "STANAGS", meaning Standardization Agreements. Those NATO countries desiring to participate in a particular agreement sign the STANAG and, subsequently, implement the terms of this agreement within their own country's forces.

It is recognized that different DEGREES of standardization may be justified in different situations, namely:

Operational compatibility
Functional interchangeability
Physical (dimensional) interchangeability
Identical equipment

In standardization, a half loaf is better than none.

The scope of the effort of the MAS is outlined in the broad fields of standardization shown in the accompanying chart (Figure 7). There are many projects in each field. Each standardization project is based on some realistic problem or operating requirement that arises in two or more of the NATO country's armed services.

There are dozens of STANAGS already in existence. Here are the titles of a few:

Marking of Lanes Through Mine Fields.
Marking of Contaminated Areas.
NATO Code Markings Used by Armed Forces of NATO Nations in Connection with Distribution of Petroleum Products.
Specification for Layout of Permanent and Mobile Airfield Lighting.
Priority Listing of Electronic Valves (Tubes).
Standardization of Radio Frequency Cables.
Rules for Conversion of U. S. Industrial Drawings for Countries Employing the Metric System.

The exact details of certain agreements are classified for obvious reasons. Note that NATO standardization agreements apply only to the portions of the military that are assigned to NATO.

Certain work concerning standardization of com-

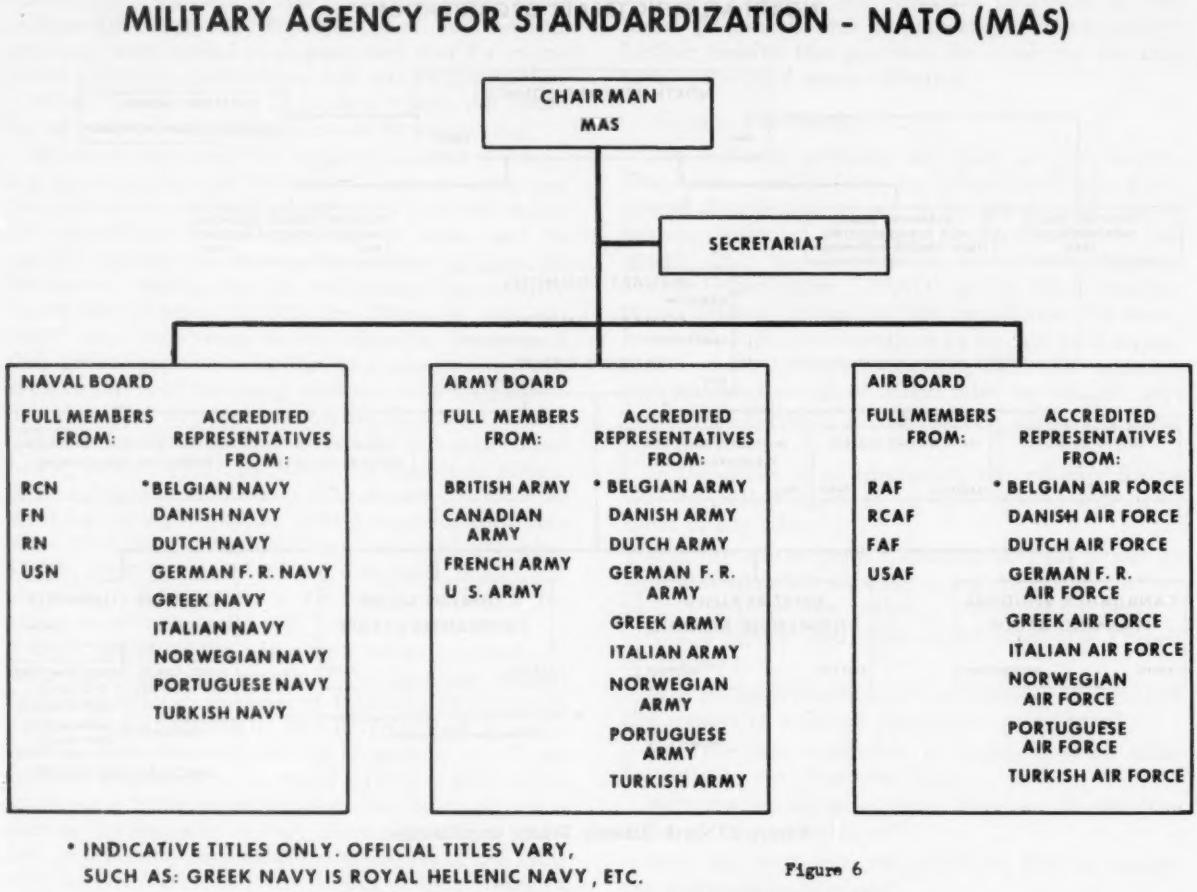



**Figure 6. Military Agency for Standardization—NATO (MAS)**

mercially produced items in the NATO countries is initiated in the International Staff of the NATO organization. This work also is processed by groups of experts and agreements arising from their work may be promulgated through the MAS as previously described.

*Other Groups Concerned With International Standardization.*

NATO is not the only group concerned with international military standardization. Some work is done within the ABC standardization framework, which refers to America, Britain and Canada. The agreements coming from this group are called ABC standards. Here are some titles:

Replenishment at Sea Procedures.

Landing of Aircraft on Aircraft Carriers.

Heat Exchanger Tubes.

Quality Standards for Potable Water.

Shock and Vibration Terminology.

**A. SEA COMMAND TACTICAL REQUIREMENTS**
**B. COMMUNICATIONS (ABC ONLY)**
**C. NAVAL CONTROL OF SHIPPING**
**D. NAVAL AIR OPERATIONS**
**E. AIR DEFENSE OF FORCES AT SEA**
**F. SURFACE FORCE OPERATIONS (ABC ONLY)**
**G. SUBMARINE OPERATIONS**
**H. ANTI-SUBMARINE OPERATIONS**
**I. MINE LAYING OPERATIONS**
**J. MINE COUNTERMEASURES OPERATIONS**
**K. OPERATIONS BY COASTAL FORCES**
**L. AMPHIBIOUS OPERATIONS**
**M. DEFENSE OF PORTS AND BASES**
**N. SEA EXERCISES AND TRAINING**
**O. LOGISTICS DOCTRINES**
**Y. DOCKING AND REFITTING**
**Z. ENGINEERING MATERIALS AND PRACTICES**

**Figure 7. Broad Fields of NATO and ABC Standardization**

You will soon be hearing more about two other international groups who will be concerned to some

extent with military standardization. (Figure 8). One is the Southeast Asian Treaty Organization (SEATO), which involves 8 nations. The other is the Inter-American Defense Board (IADB), which includes 21 republics of North and South America.

**NATO—NORTH ATLANTIC TREATY ORGANIZATION—15 NATIONS**
**ABC—AMERICAN, BRITISH, CANADIAN (MILITARY SERVICES)—3 NATIONS**
**SEATO—SOUTHEAST ASIA TREATY ORGANIZATION—8 NATIONS**
**IADB—INTER-AMERICAN DEFENSE BOARD—21 NATIONS**

**Figure 8. International Groups Military Standardization**

*Standardization Emphasizing Material Aspects.*

For many years standardization of everyday materials used by the U. S. military services has been an active thing. The bolts, nuts, paints, steels, electronic components, and, in general, materials of construction have been the object of continuous efforts. Since these items come largely from industrial sources it was only natural that groups representing the military services work—with such civilian groups as The American Standards Association (ASA), The American Society for Testing Material (ASTM), and the many technical societies and trade associations engaged in the standardization work. In fact, because of potential long-range benefits some effort also went into cooperation with the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC). Work in the latter two groups was done through the ASA.

In 1952 the 82nd Congress passed Public Law 436 formally setting up the Defense Standardization Program. This Program has grown by leaps and bounds until, at the present time, the current workload is almost 6,000 projects. These projects are divided among the military services, the "assignee" agency taking the lead in coordinating with the other agencies and with Industry to produce the desired military standardization documents.

Some of the results have been spectacular: The cost of transistors has been reduced by 40 percent. Multiple application of standard transistors in equipment has been increased by 28 times. Note that the military used 14 million transistors in 1958.

A study of engine accessories such as radiators, thermostats, relays, gas caps, lights, etc., reduced a group of 2300 engine accessories to only 78 standard items.

The Bureau of Naval Weapons studied 380 synchros, analyzing 20 characteristics of each. They standardized on 22.

**RELATION OF DEPARTMENT OF DEFENSE TO INDUSTRY STANDARDIZING BODIES**

Over three-fourths of all military items are actually developed and produced by industry. It is only natural that equipment purchased by the government should be affected by the most up-to-date practices in Industry. In fact, it is government policy to make maximum use of acceptable Industry specifications and standards wherever possible. It is also the policy to coordinate the development of military specifications and standards, with the industries concerned. This is done by invoking the aid of The American Standards Association (ASA), The American Society for Testing Materials (ASTM), the trade associations and the technical societies, which represent these industries. This interchange of standardization requirements works both ways. Industry groups send representatives to participate on Defense Standardization committees, which draw up military standards and specifications. Likewise, Defense agencies send representatives to some meetings of Industry groups doing industrial standardization work.

*Why the Military Writes Specifications.*

You may ask why the military writes its own specifications for motors, washing machines and other things which are already specified by industry groups. Actually, the military doesn't use its own specifications exclusively. Whenever an Industry specification or standard will do the job, it is the Department of Defense policy to use it. However, there are various conditions which make military documents necessary in many cases, namely:

There are no Industry standards for some items (such as, for instance, guided missiles).

Certain industrial items may be inadequate for military use (the military requires high resistance against shock and rough treatment). Some industry standards are really minimum standards and would not be satisfactory under rough treatment.

Industry standards are not controlled by the government (therefore, it is conceivable that they may be changed without the government's consent).

The Problem of obtaining large numbers of copies required for government purposes makes it expedient for the government to have its own specifications.

Government purchasing policies, such as open competitive bidding, make government type specifications desirable.

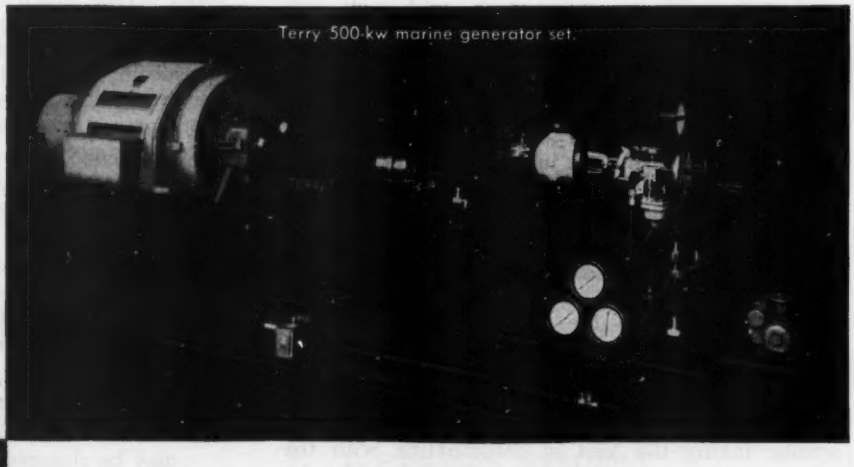
*The Need for Dynamic Standardization*

A final important point should be made concerning standardization;—it must be DYNAMIC. We need not be handcuffed to obsolete documents.

Standards and specifications must capture the great advances produced by research and development and must reflect the most up-to-date state of industrial manufacturing capability. The Department of Defense is putting increased emphasis on making use of this Industry know-how and also of the great amount of Industry effort being spent in making standards.

Practically every trade association, technical society or national standardizing body—and there are over 150—will be called upon directly or indirectly to assist in the preparation of Government standards documents. If we are to keep our national defense in a good position relative to that of other nations, the mutual cooperation of these groups is essential! Therefore, when the call comes to assist the government in this work, all should be willing to give some effort to the cause. By working together through the democratic standardization processes, we can keep our military standards DYNAMIC and our national defense STRONG!


Terry steam turbines


Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

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"BELL LABORATORIES RECORD"

# *INFRARED AND OPTICAL MASERS*

**ACKNOWLEDGMENT**

*Written by A. L. Schawlow, this article appeared in the November 1960 issue of "Bell Laboratories Record" from which it is reprinted.*

EVER SINCE THE earliest days of radio communication, there has been a steady drive toward the production and use of electromagnetic waves of higher frequencies and, correspondingly, shorter wavelengths. For this purpose, electron tubes have been refined through the years, and in the last decade they have been joined by transistors and other semiconductor devices. Today, with both tubes and semiconductor devices, we can produce wavelengths as short as about a millimeter, corresponding to a frequency of 300 kmc. However, continued progress in the construction of high-frequency devices has always been limited by some critical dimension which becomes inconveniently small as the wavelengths are reduced.

Recently, promise has come of breakthrough in this dimension-wavelength-frequency barrier. It now seems possible to apply electronic techniques to much higher frequencies using the "maser" principle. Since the invention of the first molecular-beam maser by C. H. Townes, of Columbia University, these devices have been used as frequency standards and as microwave amplifiers having very low noise. The most recent application, invented jointly by C. H. Townes and the author, will produce "coherent" high frequencies by stimulating radiation from atomic systems in the frequency band encompassing the optical and infrared regions.

What are the advantages to using high frequencies? One important application is in carrier transmission. To transmit information, no matter what kind of modulation is used, we need a band of frequencies. To transmit more information, we need a wider band of frequencies. For example, a television program needs a channel several megacycles wide, while a telephone conversation requires one of only a few kilocycles.

As the volume of information to be transmitted increases, more and wider channels are needed. With large bandwidths, we can transmit many telephone conversations and several television programs with the same equipment. Now, as the carrier frequency is raised, a given percentage bandwidth, which might be dictated by practical considerations, is a proportionately larger absolute bandwidth. Thus, more information can be transmitted with high carrier frequencies and their accompanying large bandwidths.

A second major advantage of high frequencies has to do with directivity. Higher frequencies im-

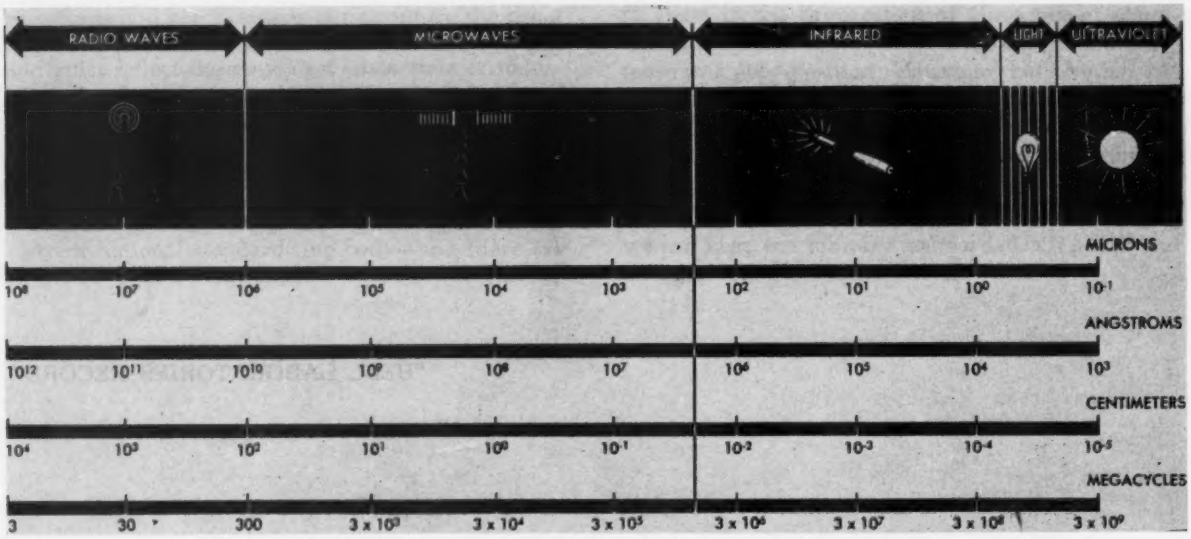



**Figure 1. Some of the major divisions of the electromagnetic frequency spectrum. Boundary near one million mc marks change in method of frequency generation. Below this point are easily generated single frequencies. Above it are broadband waves difficult to sort out for propagation purposes.**

ply shorter wavelengths, and these waves can be beamed sharply by an antenna of given size. Now that we wish to communicate with small satellites and space vehicles at great distances, there are strong reasons for seeking the highest possible directivity in a very small package.

### ELECTRON-TUBE GENERATORS

In their quest for higher frequencies and shorter wavelengths, enginers have built electron tube oscillators that produce frequencies as high as 100,000 megacycles. With harmonic generators, we can derive multiples of these frequencies as much as ten times higher. This corresponds to a wavelength of a few tenths of a millimeter—about one hundredth of an inch. The spectrum chart on this page shows this point. Below 1,000,000 mc in frequency (that is at longer wavelengths) lies the radio waves and above this point are the infrared and optical wavelengths.

All of these are electromagnetic waves; they differ primarily in wavelength or frequency. But because at this point there is an abrupt change in the way the waves are generated, there is one important difference in their nature. Radio waves generated by electron tubes have a single, definite frequency like a pure tone in sound. Light waves, on the other hand, always cover a fairly broad band of frequencies and so are more akin to noise than to a tone.

This comes about because light waves are generated by many individual atoms or molecules. Each of these emits radiation for a short interval, and is succeeded by others with a slightly different frequency. Since these individual oscillators are entirely independent, there is no connection between their phases. Thus the emitted wave has a phase that fluctuates randomly from moment to moment, and from point to point in the source. It is almost completely lacking in *coherence*. An electronic oscillator, with its phase progressing smoothly in time, *is* coherent.

Coherence in an electronic generator is an important advantage because it permits us to "beat" together waves of different frequencies, as in superheterodyne detection. Beating an incoming signal with a local oscillator in the "receiver-mixer" stage of a radio receiver permits us to convert the signal to a lower frequency band where, in some cases, it can be more easily tuned and amplified. Another advantage of a coherent source is that we can supply separate radiating elements with properly phased radiation for a directive antenna. Therefore, we can radiate waves coherent in space as well as in time.

Thus it would be most desirable to have powerful sources (amplifiers and oscillators) of coherent radiation in the infrared and optical regions of the frequency spectrum. As mentioned before, one approach to this is to continue scaling down electronic tubes to smaller dimensions. This approach has been very successful in the past and will continue, but becomes more and more difficult for signals at shorter wavelengths. Moreover, if man-made resonators of any kind are used, they become increasingly tiny and hard to make accurately because their dimensions must be comparable with a wavelength.

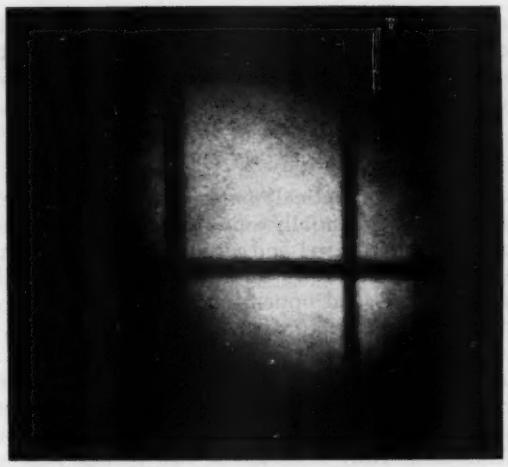


**Figure 2. Generated light from optical maser. Spot focussed by device subtends less than one-quarter degree of arc. Thus the light spot covers only a single inch square on a screen 108 inches from the maser.**

On the other hand, nature has endowed us with a copious supply of atomic, ionic and molecular resonators at almost all frequencies in this region. We need only find some way to excite them and then synchronize them so that they are made to radiate coherently. This much has been known for a long time, and indeed such light sources as gas-discharge lamps—the ordinary fluorescent light, for example—make use of radiation from excited atoms or molecules. But only since the invention of the maser has there been any indication of how the individual "radiators" might be synchronized.

The term maser is an acronym derived from "Microwave Amplification by Stimulated Emission of Radiation." Since there are now stimulated-emission devices in almost all frequency ranges, it seems best to change the "m" to stand for "molecular." Then we can retain the name for all the devices, whether microwave or not.

All atomic and molecular systems possess discrete energy levels, which are different for each kind of system. That is, they can store energy of certain fixed amounts only. An atom in its "ground" state can absorb energy from an electromagnetic wave of the right frequency, and make a transition to an excited state. Once in the excited state, the atom could lose the energy by spontaneously emitting a wave "quantum" of the same frequency as the one which originally excited it. Or, while the atom is excited, if another similar quantum comes along it can force the atom to emit its radiation and revert to the ground state.

A maser makes use of this stimulated emission. We can construct one so that in the material an excess of atoms is maintained in the upper energy state. Then an incoming wave of the proper frequency gains energy by stimulating emission from these atoms.

Figure 3 illustrates the growth of a light wave by stimulated emission. Let us suppose that the wave travels from left to right through an active medium. Active mediums contain mostly atoms in the upper state indicated by the top "ball" in the sketch. When a light wave of the proper frequency strikes one of these excited atoms, the atom is forced to emit radiation of the same frequency, giving up its excitation energy in the process. Moreover, the stimulated emission is in phase with the original, and so augments it. Thus, as the wave progresses from left to right, it grows, or is amplified, by this process of stimulated emission. On the other hand, if the wave strikes an atom in the lower energy level (indicated by the bottom ball in the sketch) it may excite the atom, losing energy in the process. Thus for amplification, the number of atoms in the upper, or excited state must outnumber those in the lower state.

We can convert this maser amplifier into an oscillator by feeding back some of the amplified output. This is done simply by terminating the active medium with reflecting end walls (figure 4). A wave which travels along the axis of the system can now bounce back and forth, returning to its starting point. In fact, it can form a standing wave system between the plates. Such sustained oscillations are obtained if the amplification of a wave traveling from one end plate to the other exceeds the loss on reflection at the ends. Of course, the signal must be extracted somehow. Making one of the end walls partly transparent permits some light to be extracted through it.

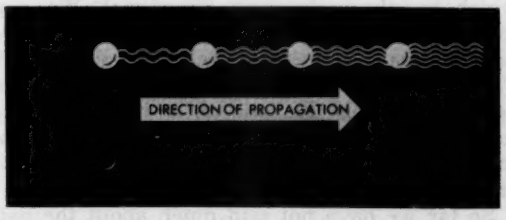



**Figure 3. Growth of a light wave by stimulated emission. Wave striking excited atom at same frequency forces it to "join" the original emission. Un-excited atom absorbs wave and ends emission.**

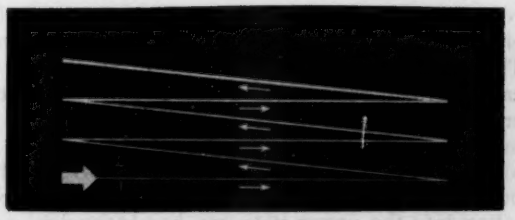


**Figure 4. One arrangement of optical maser in which wave "grows" as it bounces back and forth between reflecting walls. (Vertical dimension of the diagram has been greatly exaggerated for clarity.)**

If the maser is producing light waves in or near the visible region, there will be many thousands of wavelengths between the end plates. These reflecting plates should be flat within a small fraction of a wavelength of light, but techniques for polishing plates to such flatness were developed long ago for other optical instruments. Thus, the whole system does not have to be comparable in size with a wavelength, but can be much larger.

For microwaves, the most commonly used "tuning" element is the cavity resonator. This is a hollow box inside which the radio waves bounce. When the length of an incoming wave has the right relation to some dimension of the box, there is a resonance. Ordinarily, microwave cavity resonators are comparable in dimension to one wavelength, usually about a centimeter.

If we were to use a "large" cavity resonator for light waves, it would resonate in very many modes. However, the optical maser described here would have only the ends reflecting and, therefore would only be a good resonator for waves traveling along its axis. The other modes of the cavity resonator correspond to waves traveling in other directions. Most of these will miss the end plates entirely and will spend little time in the region of the active medium. Those only slightly off the axis will hit the end plates a few times and then pass the edge of the reflector and be lost. If the end plates are small enough in comparison with their separation, only waves traveling accurately along the axis will be amplified or generated. Then the light emerging from the partially transparent end plate will also be traveling along the axis of the system.

Thus the output of the optical maser is a wave which is inherently very directional. We expect that the radiation would initially have an accurately plane wave front, and would spread very little. The angular width of the beam of radiation should be approximately the ratio of the light wave length to the diameter of the end plates. Since the wavelength of the light is short, this is a small angle, and the light spread is very small.

So far we have not said much about the nature of the active medium. There are a great many possibilities here, and it seems likely that many different ones will ultimately be found suitable. The substance used must have a natural resonance, corresponding to a quantum transition between two energy levels at the desired operating frequency. This should preferably be a sharp resonance because broad resonances require more excitation energy in proportion to their width. Also, in the material it should be possible to keep empty the lower of the two quantum levels involved, while putting many atoms into the upper one. This excitation into the upper state can be obtained in some cases by using strong light of a suitable wavelength. In other cases, a suitably designed gas discharge may suffice. Each individual material is different, and requires its own technique. Possible materials exist in metal vapors, inert gases, and crystalline solids, and even some glasses or liquids might prove usable.

### MASER CONSTRUCTION

A solid-state optical maser can be constructed very simply. Essentially, one consists of a rod whose flat ends are silvered and whose sides are left open to admit the exciting radiation. Recently at Bell Laboratories, solid optical masers using pulsed operation have been constructed by R. J. Collins, D. F. Nelson, W. L. Bond, C. G. B. Garrett, W. K. Kaiser, and the author. Based on an arrangement proposed by T. H. Maiman of the Hughes Research Laboratories, these scientists are conducting experiments with ruby rods about two inches long and one-quarter inch in diameter. The devices have verified many of their predicted properties. In particular, operation has shown the entire signal output to be contained in a very narrow beam. In fact, most recent operations have produced a beam with a total spread of less than one-tenth of a degree.

The possible uses of an optical maser will depend on the characteristics of the individual device, just as the uses of various kinds of electron tubes differ. Nevertheless, it is possible to see some general uses arising from the basic properties of the device. In communications applications, for example, it offers the possibility of extending radio techniques to much higher carrier frequencies. Undoubtedly, higher frequencies will have advantages and applications not yet envisaged. Some of these might turn out to be as important as the long-distance transmission properties of short-wave radio which were not predicted in advance.

Optical masers would also be particularly useful in communication from earth to satellites or space vehicles. For that purpose, their very directional beam would permit communication over large distances with small amounts of power.

### POWER DENSITY

While the power output of the first continuously operating optical masers might be only a few milliwatts, nearly all the power would be beamed in a single direction. A lens or mirror could then focus the entire output to a spot of dimensions not much larger than the wavelength of light—about one-billionth of a square inch. The power density in the focal spot would then be some millions of watts per square inch. While this very high power density would exist in only a small volume, it should be enough to produce new nonlinear effects in atomic or molecular systems.

Optical masers can also provide us with sources of infrared radiation of specific frequencies with much more power than those now available. At present, if we want a single infrared wavelength,

all we can do is to filter it out of a continuous spectrum of wavelengths and in so doing we throw away most of the power. If masers do give us strong sources of appropriate wavelengths, it may be possible to use them to excite particular molecular vibrations selectively. Vigorous enough excitation eventually may be possible to influence the course of chemical reactions.

Other scientific uses promise to be numerous and varied. Among the prospects are improved atomic standards of length. These would in turn extend to much larger distances the optical interferometry methods currently used for the most precise length measurements. Scientists have even suggested that sensitive detection of length changes might make possible new tests of the theory of relativity.

There remain many difficulties to overcome before the optical maser is a practical device. But now we know at least one way to extend radio techniques to the infrared and optical region. Thus, a whole new area is open for exploration.

## RECENT OPTICAL MASER EXPERIMENTS

Recent physical experiments at Bell Laboratories have confirmed several predictions of the behavior of an optical maser. The theory of this device is discussed in the accompanying article.

In the experiments, Laboratories scientists used a synthetic ruby rod, ½ inch long and 1/5 inch in diameter. The ends of this rod were polished until extremely flat and parallel, and were covered with a reflecting, yet slightly transparent, layer of silver. This rod was held in the center of a spiral photoflash lamp and illuminated with an intense flash of ordinary white light.

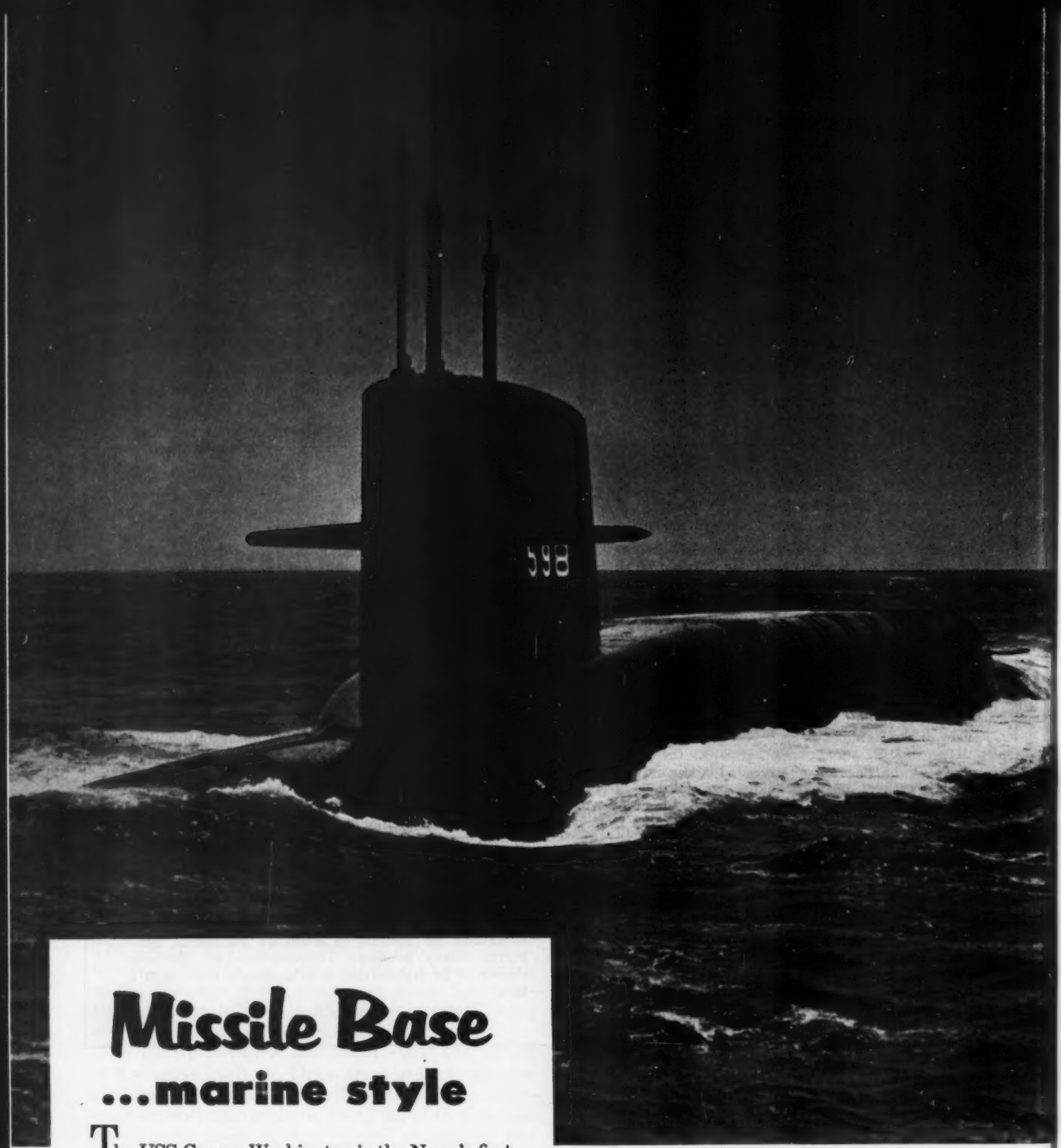
The investigators found that when the power applied to the flash lamp exceeded a certain value, a nearly parallel beam of light was emitted through the silvered ends. This light was red, like the ordinary fluorescent light from ruby, but differed from it in several important ways.

First, it was sixty times closer to being "monochromatic" (of a single frequency) than the ordinary ruby light. Second, the light is "coherent" as was demonstrated by arranging two fine, parallel slits in a thick silver coating on one end of a ruby rod. The pattern of emerging light showed the light from one slit to be interfering with the light from the other, indicating that the emitted light was in phase across the end of the rod. Third, almost all of this monochromatic light was emitted within a cone angle of only one-tenth degree. Within this cone, the intensity of the light was far higher than could be obtained by the ordinary fluorescent process.

As a communications experiment, a ruby optical maser was set up at the Holmdel, N. J., location of the Laboratories and aimed at the Murray Hill Laboratories, 25 miles away. Red flashes, clearly visible to the naked eye, registered on photo multiplier tubes. The circle illuminated by the beam at Murray Hill was only about 200 feet in diameter.

Another experiment involved transmitting pulses of light along a quarter mile of two-inch diameter circular waveguide, where the dust and fog of the atmosphere could not attenuate the beam. Photomultiplier tubes at one end of the waveguide recorded clear pulses of high-intensity light.

With further developments, a beam from an optical maser might be used for a variety of scientific applications, including communications. At present, messages can be sent only in a code based on repeated flashes. However, since the coherent light is emitted in short bursts rather than as a smooth pulse, it may eventually be possible to modulate the signal, permitting many telephone conversations or television signals to be transmitted simultaneously over such a link.



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# THE BASIS OF PHOTOELASTICITY

**THE AUTHOR**

*graduated from the U.S. Naval Academy in June of 1954. Served three years onboard the USS WISCONSIN (BB-64), in the Gunnery Department. Completed the Naval Construction and Engineering Course at M.I.T. in June of 1960. Presently attending the U.S. Naval Submarine School in New London, Conn.*

SUCCESSFUL DESIGN IS, in a large number of cases, ultimately connected with the ability to evaluate stresses produced by a given set of loads. Structural and machine designs based on nominal or average stresses continue to fail, even though strict adherence to the specified values is maintained. Only a small part of the failures can be attributed to flaws or faulty workmanship. Any design which is based on the nominal stress value is ignoring the possibility of stress concentrations. Stress levels well in excess of the average figure may originate at sharp corners, poorly designed fillets, keyways, or even scratches. Minute cracks are started, and these continue to grow until failure occurs.

There are several methods for exact stress analysis, the most outstanding of which is the theory of elasticity. Unfortunately, the mathematics is complex, even for the simpler problems. When the boundary conditions become slightly complicated the theoretical approach usually requires the use of a computer solution. At this point in the design procedure experimental methods, such as photoelasticity, are often resorted to.

The photoelastic method of stress analysis is one of the most powerful of all the experimental methods. In general, it is a type of model testing in which the models are fashioned from flat sheets of a transparent elastic material. This form of experimentation is normally thought of as being applicable to two dimensional problems only, but recent developments have been devised for the direct application of photoelasticity to three dimensional models.

Among the advantages of this method of stress analysis are that it provides a means of [1]:

1. Obtaining an over-all visual picture of the shearing stress distribution throughout the body.
2. Measurement of stress at a point, with the consequent possibility of finding actual peak values even in regions of high stress gradient.
3. Determination of stresses in two dimensional problems that cannot be solved analytically.
4. Accurate stress determination in irregular members comparable to results obtained with precise strain gauge techniques.
5. Readily obtaining qualitative results for maxi-

mum and minimum stress locations or for the determination of changes in stress distribution caused by minor design alterations.

The shortcomings of this experimental technique appear to be as follows:

1. It is an indirect method requiring the use of accurate scale models and subsequent interpretation of data for the prototype.
2. The procedures are only *readily* available to two-dimensional conditions, as three dimensional techniques are rather involved.
3. The separation of individual principal stresses at points in the interior of the model becomes difficult if great accuracy is required.
4. Stress free models must be prepared.
5. The method is limited to the determination of elastic stresses due to externally applied forces. No information can be gained about the influence of surface conditions on the prototype.

In any explanation of photoelasticity and its techniques the first topic discussed is light. According to the electromagnetic-wave theory, light is thought of as a disturbance consisting of transverse waves which are propagated along straight lines called rays. Each color in the visible spectrum is represented by a wave motion of a certain frequency. Ordinary white light is composed of a superposition of all wavelengths within the visible spectrum, the direction of the transverse vibration being entirely random.

Monochromatic light is composed of a wave motion all of one wavelength, but the direction of transverse vibration is still entirely random [2]. According to wave theory, light is composed of electromagnetic waves whose amplitudes are proportional to the electric and magnetic field strengths of the wave motion. In light, since the electric and magnetic field strengths are definitely related, we may represent the amplitude of the wave motion by a single vector. This single vector is called the light vector and is usually considered at the same position as the electric vector. The direction of the vector is normal to the path of propagation of the light and is in the plane of the wave motion. Figure 1 shows the random or chaotic motion of Ordinary or Unpolarized light.

Consider the instance in which a light beam is

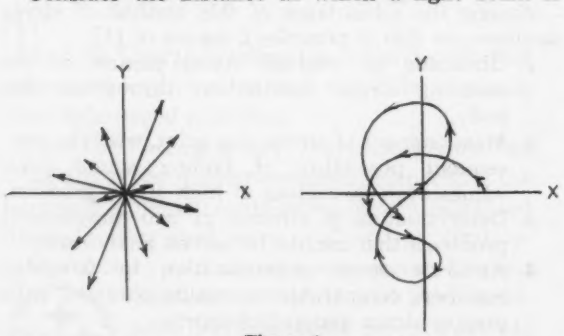


**Figure 1**

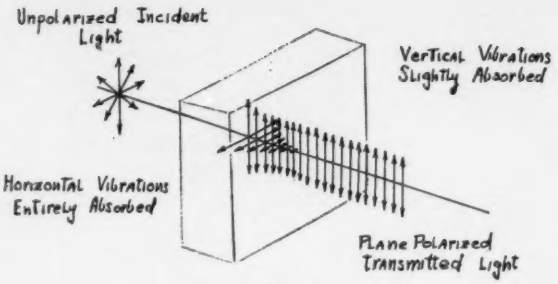


**Figure 2**

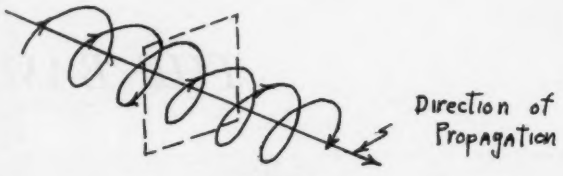


**Figure 3**

incident upon a transparent medium having the unusual property of transmitting light that is vibrating in only one plane. This is shown in figure 2, and the transmitted light is called plane polarized white light [3].

For circularly polarized light the light vector rotates around the line of propagation, and its magnitude remains constant. If, at some instant, the light vector is plotted at various positions along the line of propagation, the tips of the vectors will lie along a circular helix, as in figure 3.

Many transparent solids are considered optically inactive. Certain salt crystals and ordinary glass are in this category, and will not effect the character of the light as it passes through a given thickness of the material. The speed of the light which passes through these substances will not change even if the plane of polarization is altered. It is interesting to note, however, that certain materials are optically anisotropic. Light which passes through these substances is divided into two beams, one of which will pass through the material more rapidly than the other. This behaviour is called birefringence or double refraction. Birefringent materials have two optical axes and the speed at which the light passes through the solid depends upon the original plane of polarization. Light polarized parallel to one optical axis passes through the substance at a different speed than if it had been polarized parallel to the other axis. As plane polarized light proceeds through this type of material it is resolved into two components which are parallel to each optical axis. The two components pass through the solid, such as mica, with different velocities, and emerge from the far side with a phase difference

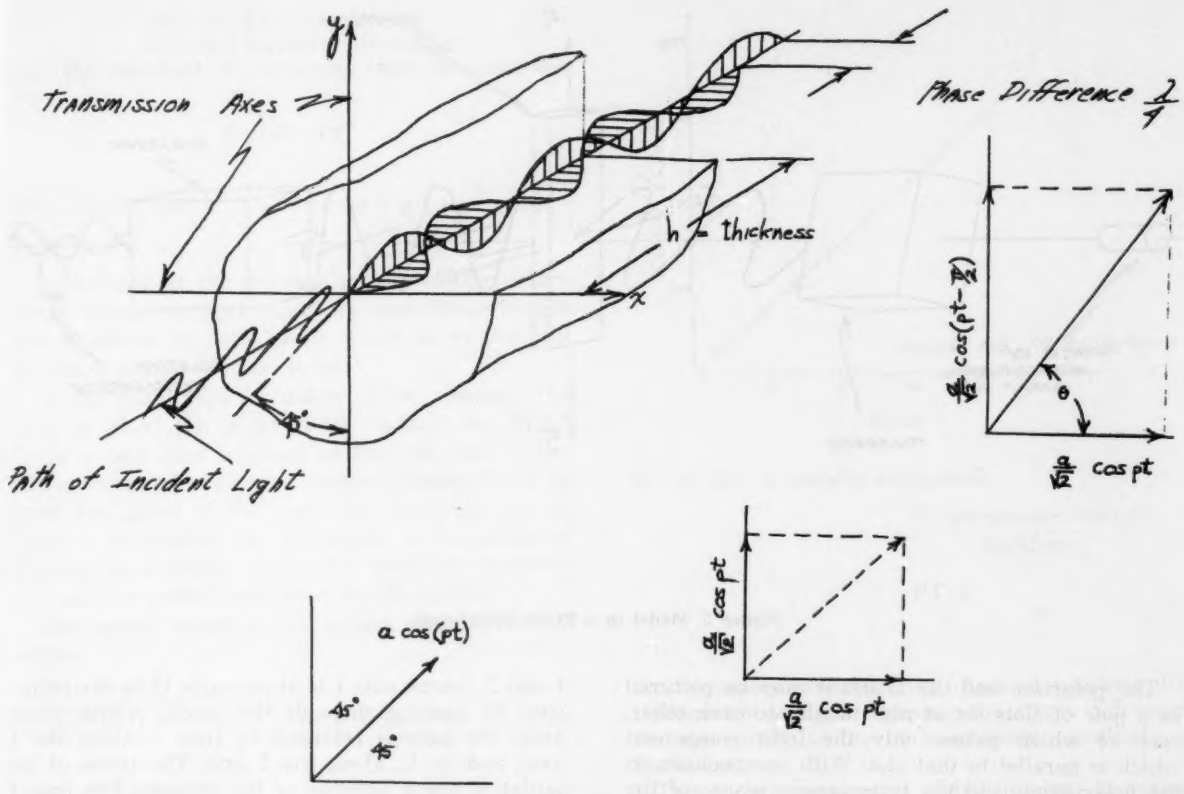


Figure 4

which is a direct function of the thickness of the crystal [4].

Materials which possess this property are called wave or retardation plates. Figure 4 shows a "quarter wave plate," which produces a relative retardation of 90 degrees between the two components [5].

The entire field of photoelasticity depends on a group of materials which become momentarily birefringent when stressed. When these materials are stressed, plane polarized light is separated into two components which are parallel to the principal planes of stress. What is even more important, the velocities at which these components are transmitted are dependent on the magnitudes of the principal stresses. These facts were first made known by Sir David Brewster in 1815. He is usually regarded as the father of photoelasticity [6].

Thus it is seen that the phase difference between the two light components depends on the difference between the two principal stresses. This difference in stress is twice the maximum shear stress, and therefore the relative retardation at any particular point is directly proportional to the shear stress [7].

As a matter of interest, the third principal stress which acts normally to the plane of the model, will effect both components equally, and will not influence the phase difference.

The primary objective in the experimental phase of the photoelastic method is to measure the double refraction induced throughout the structural model. The instrument which does this is the polariscope. An example of a plane polariscope is given in figure 5. It is the simplest form of the instrument and can be used to obtain the following quantities in the photoelastic model:

1. The directions of the principal stresses at all points (isoclinics).
2. The difference between the principal stresses at all points (isochromatics).
3. The individual values of the principal stresses along free boundaries, where the directions are either normal or tangent to the edge. (on the free boundary the principal stress normal to the boundary has a magnitude of zero, and consequently the difference between the principal stresses represents the actual numerical value along the boundary.)

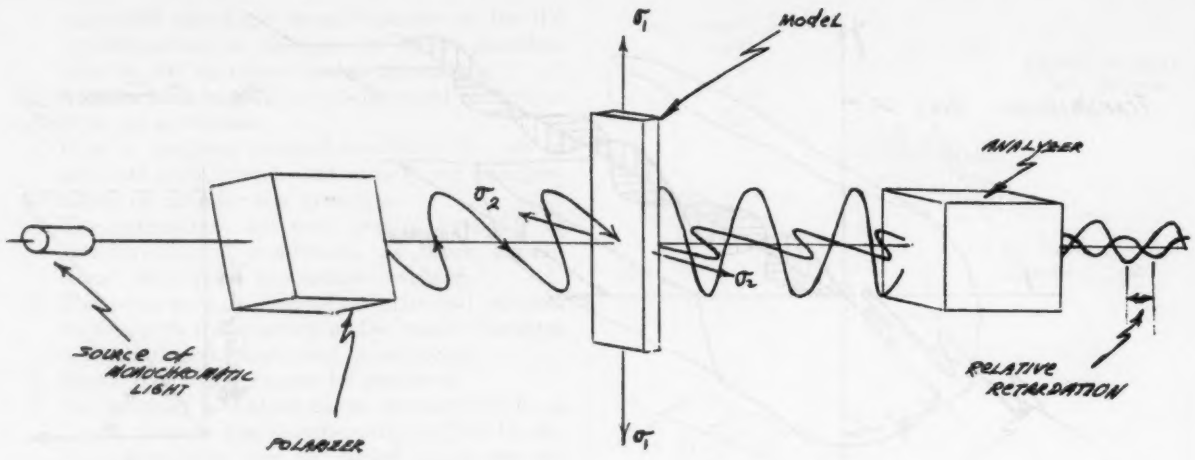


**Figure 5. Model in a Plane Polariscope.**

The polarizer and the analyzer may be pictured as a pair of slots set at right angles to each other, each of which passes only the light component which is parallel to that slot. With no specimen in the polariscope, and the transmission planes of the polarizer and the analyzer at 90 degrees, the light is completely extinguished. When a stressed model is placed in the field the plane polarized light passing through the first slot is broken up into two rays, the planes of which coincide with the directions of principal stresses in the model. The rays in these new planes may have components parallel to the slot in the analyzer, and thus some of the light is transmitted through the analyzer and produces the interference fringes or bands of constant stress difference.

To look at these concepts from a more mathematical approach the following explanation is offered [9]. The light leaving the source is non-polarized. On leaving the polarizer the light vector vibrates in only one direction, controlled by the plane of the polarizer. The magnitude of the vector as it varies with time is:

$s = a \cos (pt)$ Where s = amplitude
t = time to transverse model
p = constant
a = maximum amplitude

Looking along the axis of the polariscope, the following is seen:

The polarized light vector "a", entering the model, may transverse only along the optical axes 1 and 2, where axis 1 is at an angle G to the polarizer. In passing through the model, along these axes, the light is retarded by time $t_1$ along the 1 axis, and by $t_2$, along the 2 axis. The times of retardation are a function of the stresses. The time t is that time which is required to transverse the unstressed model.

As the light emerges from the model on its way to the analyzer, the amplitude on the 1 axis is $OB = a \cos G \cos p(t-t_1)$ (see figure 6); and the amplitude on the 2 axis is: $OC = a \sin G \cos p(t-t_2)$.

At the analyzer, the light can only enter along the plane mn i.e., the plane of the analyzer. The vector components of OB and OC lying along mn are:

$$OB' = a \sin G \cos G \cos p(t-t_1)$$
$$OC' = a \cos G \sin G \cos p(t-t_2)$$

or, noting that $2 \cos G \sin G = \sin 2G$:

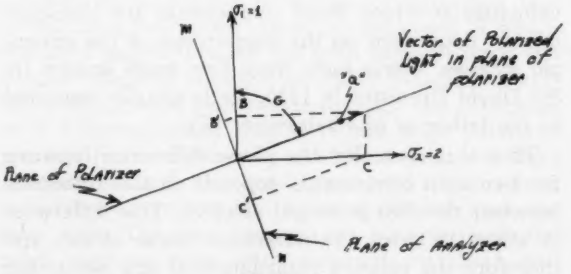


**Figure 6.**

$$OB' = a/2 \sin 2G \cos p(t - t_1)$$
$$OC' = a/2 \sin 2G \cos p(t - t_2)$$

and the resultant, R, emerging from the analyzer, is:

$$R = OB' - OC'$$

$$R = a \sin 2G \left[ \sin \left\{ p \left( \frac{t_1 - t_2}{2} \right) \right\} \sin \left\{ p \left( t - \frac{t_1 - t_2}{2} \right) \right\} \right]$$

In looking at the viewing screen of the polariscope, fringes or light bands are seen. These fringes are separated by dark bands, where R, in the final equation above, is equal to zero.

R can equal zero for either of two reasons. The first is when the angle G=0, making sin 2G=0. Such a dark spot is called an isoclinic, and occurs when either of the two principal stresses lines up with the plane of the polarizer. Isoclinics can be used to determine the directions of the principal stresses in a model. Generally speaking, isoclinics are not too useful, and must be eliminated.

The second condition for a dark spot or band is when

$$\sin p\left(\frac{t_1 - t_2}{2}\right) = 0 \text{ or } p\left(\frac{t_1 - t_2}{2}\right) = 0, \pi, 2\pi, \ldots \ldots n\pi$$

$$t_1 - t_2 = 0, 2/pn\,\pi$$

This will give rise to isochromatics, which are much more important than isoclinics.

The velocities of light along the 1 and 2 axes are:

$$v_1 = \frac{h}{t - t_1}$$

$$v_2 = \frac{h}{t - t_2}, \text{ where h is the model thickness.}$$

thus:

$$t_1 - t_2 = h(1/v_2 - 1/v_1) = \frac{h(v_1 - v_2)}{v^2},$$

providing that $v_1$ and $v_2$ are not greatly different than v, the velocity in the unstressed model. Experimental evidence verifies the validity of this assumption.

Experimentally, from the photoelastic effect, we know that: $t_1 - t_2 = h K (\sigma_1 - \sigma_2)$, where K is a constant.

Thus, where isochromatics occur,

$$h K \left( - \right) = 0, \frac{2n}{p}$$

$$= 0, \frac{2n}{p} \frac{1}{hK}$$

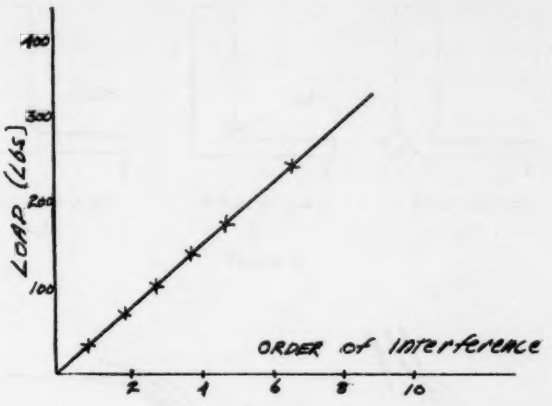


Figure 7.

or, as this is usually expressed:

$$= \frac{\text{Fringe constant order n}}{\text{thickness}}$$

$$= \frac{\text{F.C. n}}{\text{h}}$$

Isochromatics are, therefore, lines of constant differences of principal stresses, the stress difference for any particular line or band being a multiple of the order n.

There are several ways of determining the fringe constant, which is a property of a given material. The simplest method is a simple tension test, with the dimensions in figure 7 [10].

The specimen is loaded slowly. As loading is commenced the specimen is first dark (at no load), goes through brightness to darkness (this is the first order), then brightness to darkness again (second order), and so on. Maximum darkness each time occurs at some multiple (order) of the load for the first darkness. A plot of P vs n gives a usable value of the slope, and the fringe constant is equal to this value.

$$\text{F.C.} = \frac{P}{b\,n}, \quad \frac{\text{lb}}{\text{in-order}}$$

Bakelite has a F. C. of about 80 lb/in-order. Glass, a relatively insensitive material, has a constant of over 300 [11].

The isoclinics resulting from a plane polariscope are generally not too useful, and serve to mask the more important isochromatics. To destroy the isoclinics quarter wave plates are inserted between the polarizer and the model, and between the model and the analyzer. A quarter wave plate is seen in figure 4. When the entering light vector is at 45 degrees to the axes of the quarter wave plate, the plane polarized light is transformed into circularly polarized light, since the resultant vector is of constant magnitude, rotating uniformly with time. It is

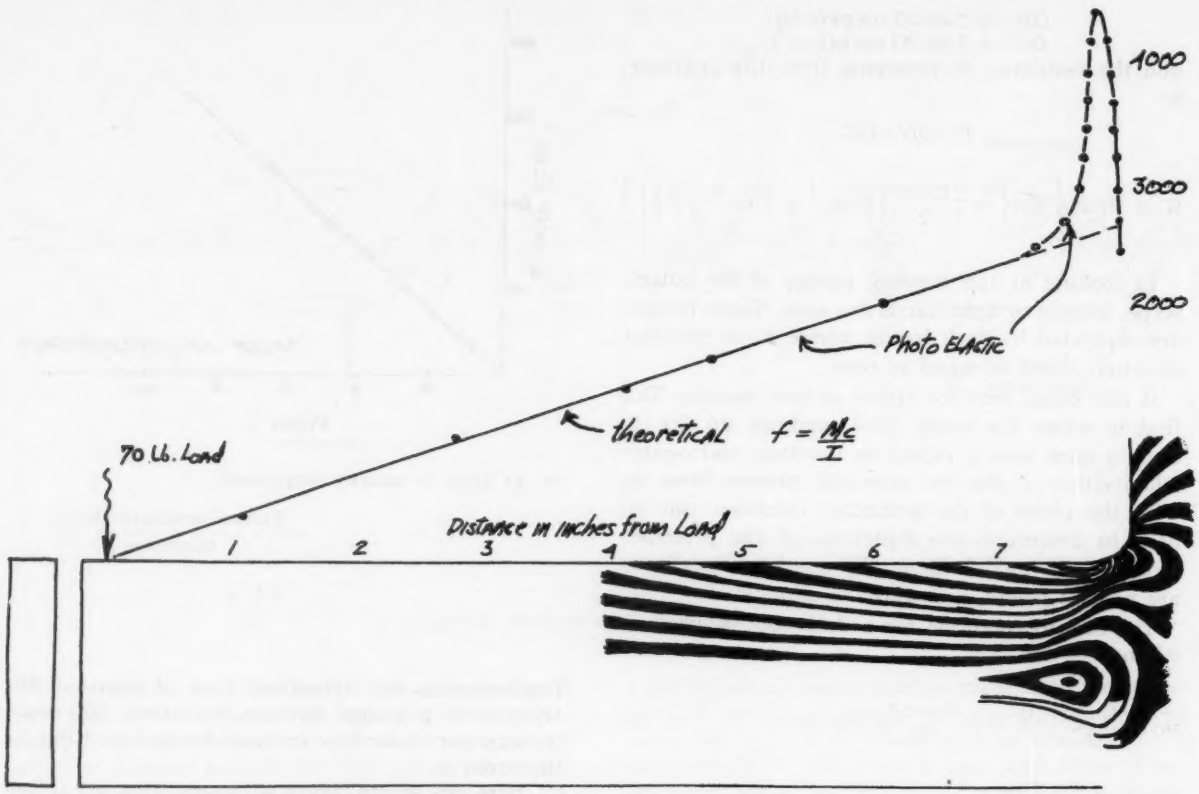


**Figure 8. Stress concentration at the fixed end of a cantilever beam. (Note the concentration of lines in the region of high stress)**

well to note that a quarter wave plate is such for one given wavelength of light, only.

The polariscope which utilizes the two quarter wave plates is known as a circular polariscope. After the light leaves the first quarter wave plate, it is circularly polarized, and in this condition enters the model. Since the properties of circularly polarized light are the same in all directions, the light vector remains unaffected by the orientations of the principal stresses in the model, but is affected only by their magnitudes. The light vector passes only along the axes of principal stresses in the model. Thus two waves, each retarded to a different degree, emerge from the model and enter the second quarter wave plate, which returns the light to the plane polarized condition. The resultant light vector, at the exit of the analyzer, may be expressed by an equation similar to that on page 55. The factor $\sin p\left(\frac{(t_1-t_2)}{2}\right)$ still exists, and the isochromatics are retained. The term sin 2G does not appear in the equation, and the isoclinics associated with that angular dependence disappear.

An example of the photoelastic method is seen in figure 8. Though only a small portion of the overall pattern is shown, the shearing stress distribution is clearly shown for the region of interest. The concentration of lines indicates the area of highest stress. Both the theoretical results obtained from the simple beam formula, f=Mc/I, and those determined from the photoelastic analysis have been plotted. The two methods agree up to a point within one inch from the base (the region of the fillet). From the value of the maximum stress one can compute the "stress concentration factor," which is defined as the maximum true stress divided by the maximum apparent stress as computed from the simple theory [12]. For the example at hand, the maximum stress computed by the photoelastic method is 4350 psi and that determined by the beam formula is 2700. The ratio of these two values gives a stress concentration factor of 1.61 for this particular case. In order to find the maximum true stress in any geometrically similar beam one would just compute the maximum stress from the formula and then multiply the quantity by the stress concentration factor, 1.61, to find the true value. It has been found that the stress concentration factor is a function of the fillet radius, the depth of the beam, and the depth of the support. Various proportions have been set up in curves so that the designer can easily determine the proper stress concentration

factor for any beam [13]. In general, the investigator locates the line of zero difference between principal stresses (the zeroeth order), counts lines from there to the line in question, and the stress value is the F. C. times the number of lines counted. Another method is to watch the stress lines being formed as the model is loaded and to count them as they pass a given point [14].

The photoelastic material selected for a given model is always the result of a compromise to obtain the largest number of desirable properties with the fewest undesirable characteristics. There are certain general properties which should be sought for even if they cannot all be obtained. Among these desirable characteristics are the following [15]:

1. The material must transmit light.
2. It must possess the necessary birefringence; that is, when under load it must polarize light and transmit it along the principal planes with velocities which are dependent on the principal stress magnitudes.
3. The material should be easy to fabricate, and free from creep under steadily applied loads.
4. Freedom from initial internal stresses is very desirable.
5. The material should resist the formation of residual stresses which tend to develop with time.
6. The material should have a linear stress strain characteristic and a high proportional limit. so that reasonably high loads can be sustained.
7. It should have a low fringe constant.
8. It should be available in large sheets and reasonably priced.

Glass is the original photoelastic material, but is only rarely used now because of the difficulty in machining it to intricate shapes and its optical insensitivity (high Fringe Constant). The most popular material used today is Bakelite BT-61-893. It has good strength properties, a relatively high modulus of elasticity, and a fairly low Fringe Constant. A peculiar characteristic of this material is that when subjected to load at an elevated temperature (above 212°F) and gradually cooled to room temperature the strains which it possessed at the higher temperature remain locked in. This makes it suitable for three dimensional analysis [16]. There are many other materials used in the technique, but the most interesting is Gelatin. For applications involving stresses produced by the dead weight of the structure, such as gravity dams and foundations, gelatin is very successful.

An example of the photoelastic method is one in which the stresses in fillets are defined to such an extent that the basic design is improved to the point where the stress concentration factor is reduced by 68 per cent. The original part is seen in figure 9 (a), and the succeeding modifications in parts (b) and

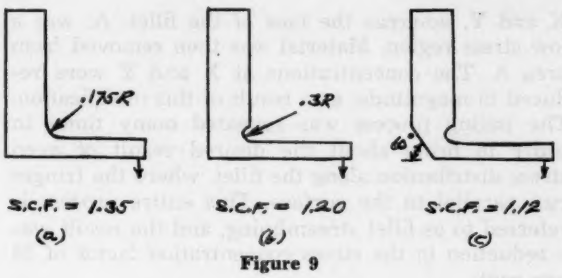


Figure 9

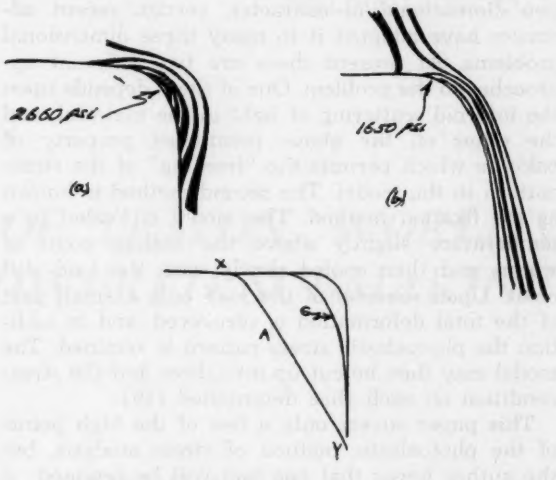


Figure 10

(c) of the same figure. This particular example of undercutting a fillet is not usually considered necessary except where space limitations exist [17].

A second example of photoelastic technique is seen in figure 10, which shows the actual photoelastic stress pattern used in the improvement of a fillet design. The original fillet is seen in part (a) of the figure.

This particular example is an excellent demonstration of the two basic methods of design improvement, which are:

1. Reduce the cross sectional area of the low stressed regions in order to reduce the total weight of the part.
2. Increase the cross sectional area of the region of maximum stress, to obtain a more evenly distributed maximum stress condition.

These ideas are outgrowths of the concept of perfect design, i.e., "from a theoretical point of view—the perfect design exists where the disposition of material comprising the part is such that initiation of failure at all points is only just avoided in service" [18]. In order to eliminate the S.C.F. of 1.61, the original fillet was increased to the maximum allowable limit, profile XAY. A photoelastic study revealed the fact that high stress regions existed at

X and Y, whereas the face of the fillet, A, was a low stress region. Material was then removed from area A. The concentrations at X and Y were reduced in magnitude, as a result of this modification. The paring process was repeated many times in order to bring about the desired result of even stress distribution along the fillet, where the fringes run parallel to the surface. This entire process is referred to as fillet streamlining, and the result was a reduction in the stress concentration factor of 38 per cent.

Although the photoelastic analysis is primarily two dimensional in character, certain recent advances have adapted it to many three dimensional problems. At present there are two different approaches to the problem. One of these depends upon the internal scattering of light in the material, and the other on the above mentioned property of bakelite which permits the "freezing" of the stress pattern in the model. The second method is known as the fixation method. The model is loaded to a temperature slightly above the boiling point of water, and then cooled slowly with the load still on it. Upon removal of the load only a small part of the total deformation is recovered, and in addition the photoelastic stress pattern is retained. The model may then be cut up into slices and the stress condition on each slice determined [19].

This paper covers only a few of the high points of the photoelastic method of stress analysis, but the author hopes that one fact will be retained: it is a convenient engineering tool which can be applied, in many cases, with the aid of a small amount of arithmetic even though there is much involved mathematics behind the theory.


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## SOVIET SUBMARINE BASES

Soviet submarines operate from various bases located around the periphery of the Soviet Union. Among the principal bases are the Kola Inlet in the Barents Sea or Northern area (which affords access to the North Atlantic shipping lanes), Kronshtadt in the Baltic Sea, Sevastopol in the Black Sea and Vladivostok and Petropavlovsk in the Pacific. The Soviets also have an important submarine base in Albania.

"WELDING JOURNAL"

# *WELDING OF TRITON, WORLD'S LARGEST NUCLEAR-POWERED SUBMARINE*

**ACKNOWLEDGMENT**

*This article was first presented by the author, G. W. Kirkley, Jr., at the 41st Annual Meeting of the American Welding Society. It appeared in the September 1960 issue of "Welding Journal" from which it is reprinted.*

On August 19, 1958, *Triton*, the world's largest undersea craft, slid down the building ways at General Dynamics' Electric Boat Division in Groton, Conn., before a crowd of 34,000 people. This ship, which represents the latest design and fabrication techniques in the construction of atomic submarines completed her builders' trials a few months ago and is now a commissioned ship in the U.S. Navy.

The *Triton*'s purpose is to be a radar picket scout in the far fringes of a Navy task force. With her advanced electronic and radar equipment, she can be used as an off-shore listening post, radioing back warnings of approaches by air, on the surface or under the sea.

The unbelievable accomplishments of the *Triton*'s famous predecessors are well known. *Nautilus* and *Skate* both traveled under the North Pole ice pack and *Seawolf* established a record by staying submerged for 60 days. Likewise, the *Triton* has already written naval history by remaining submerged while traveling around the world in 84 days.

The *Triton* dwarfs her famous predecessors. She is 66 ft. longer than any other U. S. submarine and her displacement is twice that of the 3000 ton *Nautilus* (see Figure 1).

A submarine is an extremely complex weapons system. As a result, a welding program is quite

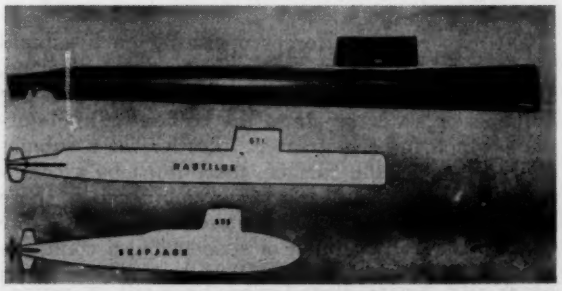


**Figure 1. TRITON's 447-ft length dwarfs the famous NAUTILUS.**

diversified. Hull plating may require heavy multipass welds while hundreds of feet of small-diameter reactor-instrumentation tubing only require a minimum size deposit. Regardless of the material involved or the size of the deposit, all submarine welds must be of the highest quality.

### NEW DESIGN CONCEPTS

One of the important "firsts" of the *Triton* were her two reactors. These twin reactors incorporate a number of major design advances in efficiency and refueling techniques.

She is the first to be designed with three decks. All previous A-boats have been strictly two-level. The *Triton* is the first with a dial telephone system throughout, monitored by a 40-line switchboard. Other submarines use simple sound-powered phones.

As can be imagined, with the many "firsts" of the *Triton*, she presented many design and fabrication challenges for the welding engineer.

The *Triton's* hull is of 100 per cent welded construction. For the most part, the only mechanical type connections are her deck hatches and torpedo tube doors.

All submarine welding is fusion welding. In the welding of the *Triton's* hull, both the manual shielded metal-arc and the automatic submerged-arc processes were used. Her reactor and steam piping were welded using a combination of the inert-gas-shielded tungsten-arc and the metal-arc processes. Copper tubing was silver brazed. The heavy lead shielding around the reactor compartment was cast and welded by lead burning.

Almost 400,000 pounds of welding filler metal, in some 50 to 60 different sizes and alloys were required to join the *Triton*'s hull and internals.

### DIVING AND SURFACING

The *Triton* is made up of a hull within a hull (see Figure 2). The thicker internal hull is the pressure hull, or that portion that is designed to withstand full submergence pressure. The outer, and somewhat thinner, hull forms the ballast, negative, trim and drain, and other various tanks with the inner hull. It is by controlled flooding and blowing of tanks that the submarine is able to submerge and rise [1].

The two opposing forces operating on a submarine are gravity, which tends to sink the submarine, and buoyancy, which tends to float it. Relative volumes of water or air in the ballast tanks determine which force is greater. In order for a submarine to float on the surface, there must be a condition of positive buoyancy. For submerging, there must be a condition of negative buoyancy. If the boat is to stay in a state of suspension, a condition of neutral buoyancy is established. A submarine is set for negative buoyancy only at the start of submergence. With the dive once started, the craft is

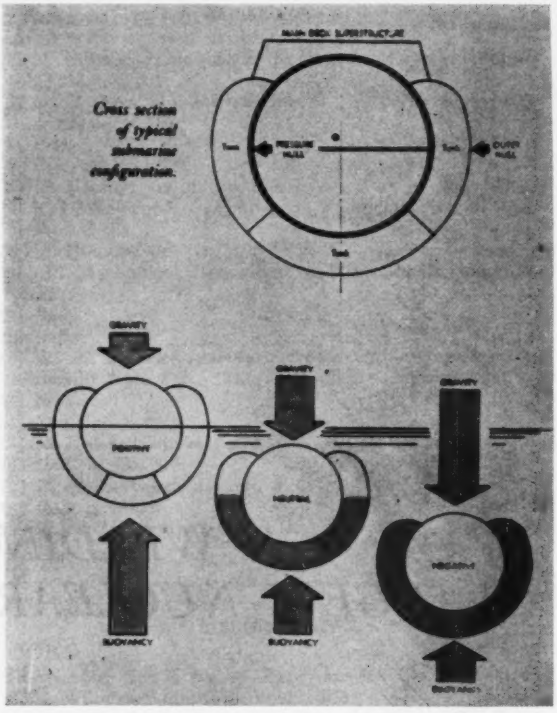


**Figure 2. A typical submarine cross section and how the forces of gravity and buoyancy tend to raise or lower the ship.**

brought to a condition of neutral buoyancy so that its depth can be controlled by the ship's motors and diving controls.

### HULL SUBASSEMBLIES

As hull plates were received, they were inspected for thickness and internal laminations or inclusions. Figure 3 shows an ultrasonic reflectoscope in use.

**Figure 3. Receiving inspection by ultrasonics. The boundary of 24-in. squares are searched first. Then the grid diagonals from corner to corner are examined.**

Impulses of ultrasonic vibrations are introduced into the material by means of a searching unit containing a quartz crystal. When the vibrations are interrupted by an internal defect, or by the far side of the plate, they are reflected back and appear on a screen as vertical indications along a square-wave marker. By proper interpretation of these pulses, discontinuities are shown.

Hull plating was purchased to Navy Specification MIL-S-16113B Grade HT—high tensile. Chemistry and mechanical properties are shown in Table 1.

In the fabrication of the *Triton*, first the vertical bulkheads were prefabricated as subassemblies. Bulkheads are designed as structural members, as well as for separating the ship into watertight compartments. Figure 4 shows a typical bulkhead for the *Triton*. The bulkhead proper (Mark 1) was made up of several plates. The outside diameter was oxygen cut oversized to allow for any weld shrinkage and subsequent fitting to the hull cylinders. Generally, welding began in the center and progressed outward in all directions simultaneously. The horizontal girders (Mark 2), the panel stiffeners (Mark 3) and floor stiffeners (Mark 4) were next partially joined by tack welding. These pieces were then finished welded by controlled welding techniques to minimize distortion and residual stresses.

All other stiffeners and plating were similarly tack welded for alignment and then finish welded using the same controlled techniques. The lower portion of this particular bulkhead incorporates a tank. The bulkhead diameter is over 35 feet.

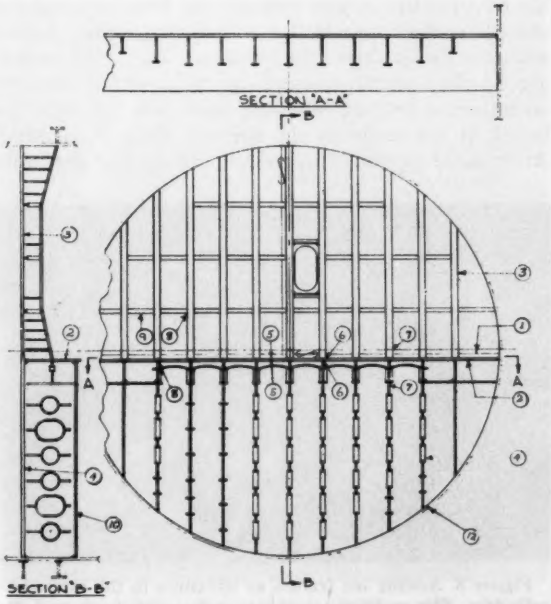


**Figure 4. Vertical bulkhead configuration including tank.**

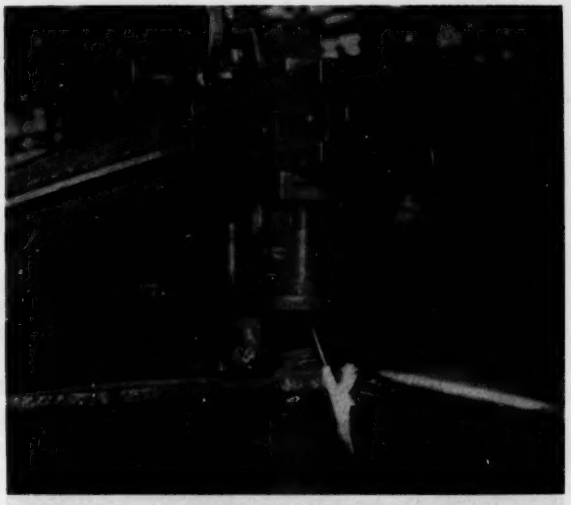

**Figure 5. Two mechanically driven cutting torches were used to make hull-plate weld preparation.**

### INNER-HULL SUBASSEMBLIES

Simultaneous with the fabrication of vertical bulkheads, the *Triton*'s inner or pressure-hull cylinders were also being fabricated as subassemblies. The first step in the fabrication of inner-hull cylinders was the oxygen beveling of each of the four edges of the three plates that made up a cylinder. The plate edges intended to be fitted and welded together to form the longitudinal seams of a cylinder were unsymmetrically double beveled so that the larger portion of the bevel was on the outside of the cylinder. This was to allow for the majority of welding to be accomplished on a positioner by automatic welding.

Figure 5 shows a double-beveling machine preparing a symmetrical bevel on plate edges intended to be the ends of the cylinder and, hence, to be joined by butt or circumferential welds. Since these welds were made in the fixed position on the building ways by the manual metal-arc process, a symmetrical bevel was used. Two oxygen-cutting torches were positioned at the proper angle, one trailing the other by several inches. Both were mounted on a power-driven carriage traveling at a predetermined speed, depending on the thickness of the plate to be cut.

After oxygen beveling, the three hull plates were cold bent on plate rollers to form a circular inner-hull cylinder (Figure 6), These recently installed rollers, which weigh 375 tons are the largest ever built and required 10 railroad cars to transport them from their point of manufacture to our plant in Groton, Conn.

Figure 7 shows the inner-hull cylinder subassembly ready for depositing the submerged-arc portion of the longitudinal weld seams. The three rolled plates were positioned around the temporary

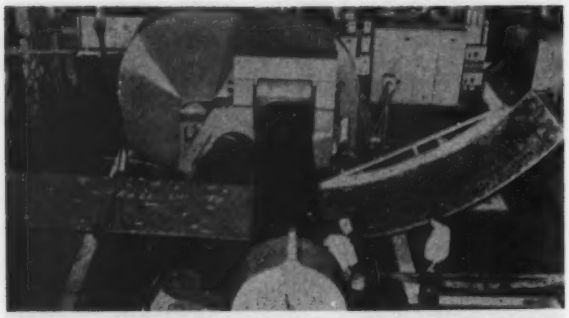

**Figure 6. Cold bending one of the three plates that formed each hull cylinder. Man in background is checking curvature against template.**

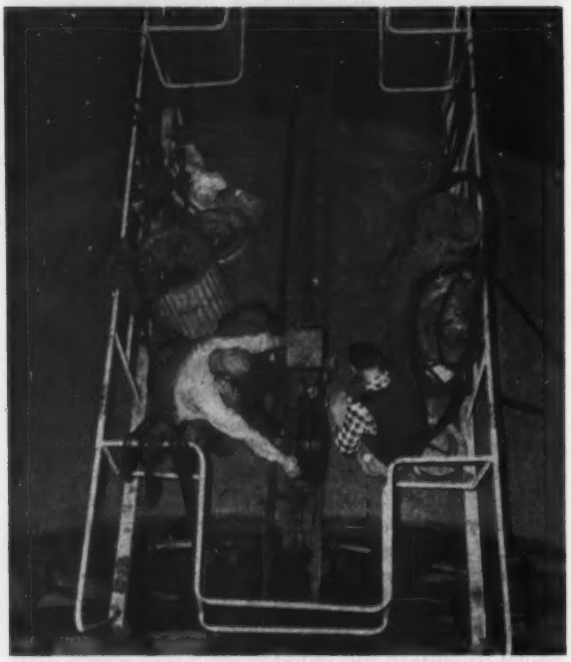

**Figure 7. Submerged-arc welding of longitudinal inner-hull seam. The heavy temporary I-beam spiders used to hold the close circularity tolerance are shown in the foreground.**

erection spiders and aligning rings. As can be seen, the plates were held to hull diameter and circularity by tack welding temporary aligning clips to the hull plates and erection spiders. Where a vertical bulkhead was incorporated into a hull cylinder, the prefabricated bulkhead was lowered onto a single rolled plate; next, the other two plates and temporary erection spiders and aligning rings were put into place.

The underside of this unsymmetrical joint was welded first by the manual metal-arc process. Due to the obstruction of the temporary erection spiders, it was not possible to weld both sides by the submerged-arc process. All manual metal-arc hull

**TABLE 1**
***MIL-S-16113B—High-tensile Steel***

Chemistry, %
- C, 0.18 max
- Mn, 1.30 max
- P, 0.040 max
- S, 0.050 max
- Si, 0.15-0.35
- Cu, 0.35 max
- Ni, 0.25 max
- V, 0.02 min
- Ti, 0.005 min
- Cr, 0.15 max
- Mo, 0.06 max

Mechanical properties
- Ultimate strength—85,000 to 92,000 psi, depending on thickness
- Minimum yield point—42,000 to 50,000 psi, depending on thickness
- Minimum longitudinal elongation—20%
- Minimum transverse elongation—16-20%, depending on thickness

welding on the *Triton* was performed by electrodes complying to the requirements of Table 2. After back chipping to sound metal from the outside, the cylinders were positioned as shown with weld seams in the flat position, so that the major portion of the deposit could be made by the submerged-arc process. Also shown in Figure 7 are the tracks used to guide the welding head, the temporary "start-up" and "run-off" tabs at each end of the weld groove and the flux recovery unit. The number of progressions of the welding head depended on plate thickness.

The next step in the prefabrication of the *Triton*'s inner-hull section was the addition of external tee frames as stiffeners to the outside of the cylinders. The web of the tee frames were symmetrically double beveled by oxygen cutting and fitted around the outside of the inner hull. Welding was accomplished with the setup shown in Figure 8. Two submerged-arc welding machines were operated simultaneously on adjacent frames. Welding wire was fed into the bevel at an angle of 22 degrees from horizontal. After welding was finished on one side of the web,

**Figure 8. Adding tee frames as stiffeners to the inner-hull cylinders. The welding machines were stationary and the cylinder was rotated.**

TABLE 2
*MIL-E-18038—Type MIL-8016 Low-hydrogen High-tensile Electrodes*

Chemistry, %
C, 0.12 max
Mn, 0.40-1.10
P, 0.03 max
S, 0.04 max
Si, 0.05-0.06
Ni, 0.25 max
V, 0.05 max
Cr, 0.15 max
Mo, 0.05 max
Mechanical properties
Ultimate strength—80,000 psi min (stress relieved)
Minimum yield strength—70,000 psi (as-welded and stress relieved)
Minimum elongation—20% in 2 in. (as-welded and stress relieved)
Charpy V-notch impact—20 ft-lb at 0° F
Brinell hardness—180-205 (as-welded and stress relieved)

the machines were alternated and welding was completed by the deposit on the opposite side. A previously completed longitudinal seam is visible under the white painted line running the length of the cylinder. The latter weld was made with the cylinder stationary and the welding head in motion along guide rails. In the welding of tee frames to hull cylinder, the reverse technique was used; the welding heads were held stationary and the weldment was moved under the arc. Figure 9 shows a large-diameter inner-hull cylinder with tee frames added.

### KEEL LAYING

While the vertical bulkheads, inner-hull cylinders and tee frames were being fabricated as subassemblies, the flat plate and vertical keels were also being prefabricated (see lower portion, Figure 10). In conjunction with keel fabrication, the first outer-hull plate, or A strake, and floor frames were welded to the keel. This subassembly was then moved by cranes to the wooden keel-blocks on the building ways during the keel-laying ceremony.

Without fanfare, the *Triton's* keel was laid on May 29, 1956. She was launched 27 months later.

The vertical keel was slotted to allow for the external framing of the previously fabricated inner-hull cylinder when it was landed on the keel. Filler plates were added to the vertical keel in the area of the cutouts to make the structure watertight.

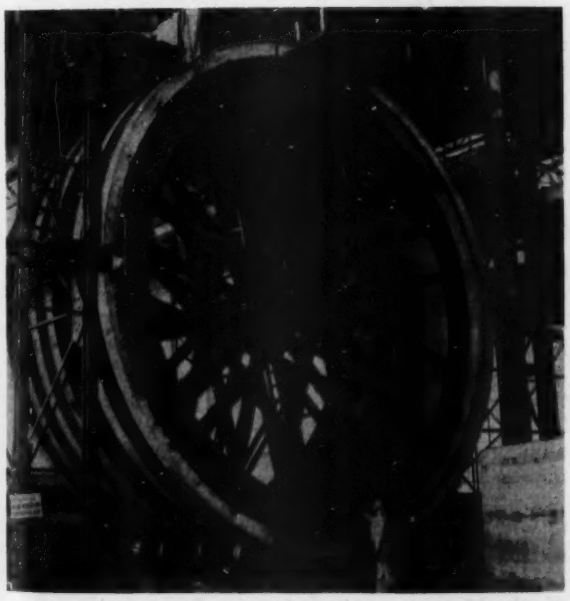

**Figure 9. A large diameter inner-hull section with tee frames. The man gives an indication of TRITON's size.**

### BUILDING-WAYS CONSTRUCTION

Construction progressed as additional prefabricated hull cylinders were moved onto the building ways. The centermost hull cylinders were landed first and then alternate forward and aft cylinders followed. The upper portion of Figure 11 shows the welding sequence for the first three inner-hull butt welds. Each butt weld was made by pairs of operators working diametrically opposite each other using manual stick electrodes deposited in a symmetrically double-beveled joint. Figure 12 shows these welds in progress. Since the *Triton's* building-

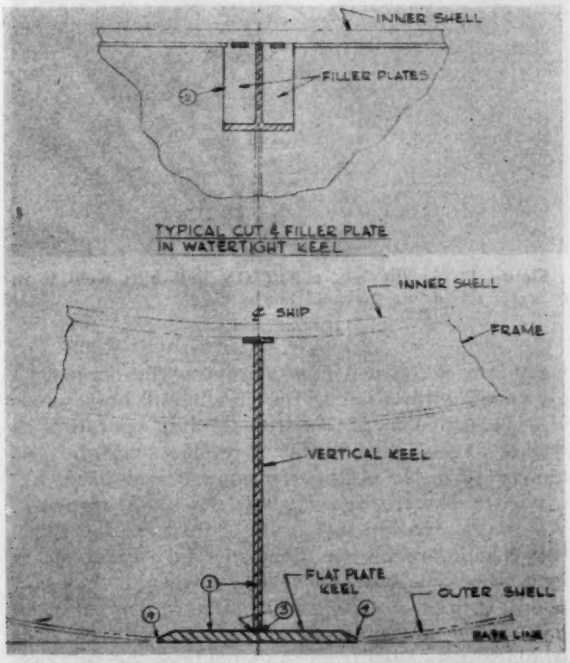


**Figure 10. TRITON's keel configuration. It is generally believed that the keel is the first construction assembly of a ship. Actually, prefabrication was going on many months in advance of TRITON's keel-laying ceremony.**

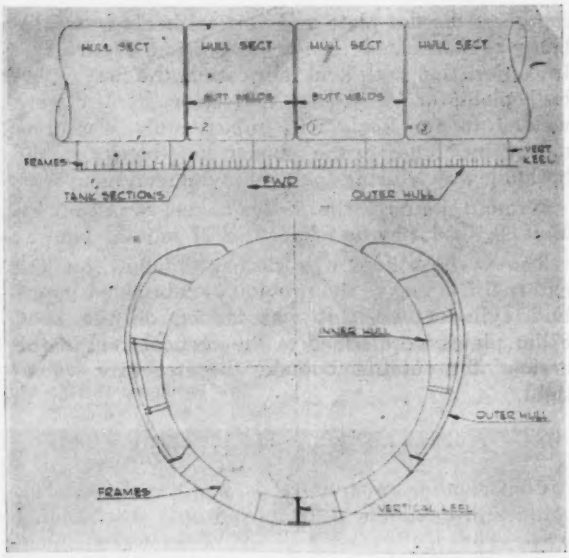


**Figure 11. The sequence of butt welding cylinders. Starting amidships, cylinders were welded together alternating forward and aft. The lower portion shows the transverse framing between the inner and outer hull.**

**Figure 12. At the left, a TRITON hull butt weld is in progress under the plywood house.**

ways fabrication was done outdoors, the temporary plywood house around the inner-hull butt welds was necessary to protect the welding operators as well as localize the 100-200° F preheat and interpass temperature. No postheat treatment was used.

All welds were deposited by the block sequence. Welding started on the inside of the cylinder and a full circumference was deposited to a depth of ½ inch. Block length and space between blocks was about 18 inches. After back gouging from the opposite side to sound metal, ½ inch of weld was similarly deposited from the outside of the cylinder. Then the weld was completed by operators depositing blocks simultaneously on the inside and outside. By this technique, shrinkage was uniform and the cylinders were aligned to the true centerline of the ship. To minimize residual stresses in the area of the keel, no inner-hull cylinders, except for the first landed, or amidship cylinders, were welded to the keel until hull butt welding was completed. As the inner-hull cylinders were joined to each other, additional outer-hull plates were welded to the keel and A-strake assembly. As was previously mentioned, the inner hull was prefabricated as a series of cylinders and, therefore, the work could be positioned and welded in the flat position. The outer hull, however, was added plate by plate over the building ways. Welding was in a fixed position, ranging from overhead, while working on the plates near the keel, to horizontal and to flat, as more plates were added. In the fabrication of the outer hull, butt welds were made first, then longitudinal welds were deposited by working from the previously made butt welds. The joint geometry of the outer-hull plating was a symmetrical double vee. Welding was done from both sides, simultaneously, to control distortion. As additional outer-hull plates were built up from the keel, transverse frames were welded to the inner and outer hull (see lower portion, Figure 1). To maintain alignment and to balance stresses, transverse frames were first tack welded to temporary jigs around the curvature of the hulls. To make these welds, the operators had to work in the area between the two hulls. Each transverse frame was considered as a separate attachment and, as such, was given the same careful attention to welding details as were the heavy inner-hull welds.

### HULL INSPECTION

All longitudinal seams and circumferential butt welds in the *Triton*'s hull were radiographically inspected for their entire length. Where practical, inner-hull butt welds were radiographed using a cobalt source and a panoramic camera. By this technique it was possible to locate the source on the centerline of the ship and make one exposure for the full circumference of the weld, over 100 feet.

### REACTOR COMPARTMENT

To prove out the *Triton*'s twin-reactor concept of nuclear design, a prototype of the reactor compartment and engine room was built for the Atomic Energy Commission near General Electric's Knolls Atomic Power Laboratory in Schenectady, N. Y. (Figure 13). This "land-based" submarine prototype has been valuable in the prediction of the *Triton*'s performance. It is presently "steaming along" under full nuclear power, giving new information in the field of reactor technology.

The atomic-submarine hull must not only be able to withstand the tremendous pressure of great submergence depths, but it must also be designed for the extreme shock of depth charges. To prove out the machinery, components are subjected to a series of tests simulating shock conditions. Often these

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**Figure 13. A land-based submarine was constructed for the AEC to prove out TRITON's reactor and engine room.**

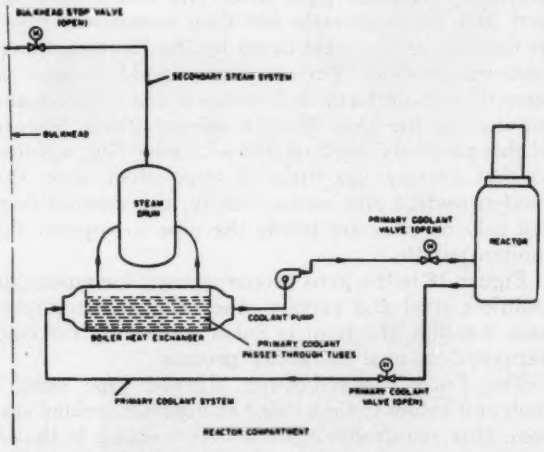


**Figure 14. TRITON's pressurized water-reactor complex.**

tests are conducted at extreme angles of roll and pitch.

Figure 14 shows a typical schematic diagram of a reactor compartment [1]. A nuclear reactor such as this is usually referred to as a thermal reactor because the nuclear fission produced occurs in the low-velocity thermal-energy range. Heat is conveyed from the pressurized-water reactor to the boiler heat exchanger through the primary-coolant piping. The steam energy generated in the heat exchanger is delivered to the *Triton*'s turbines by the secondary or steam piping system.

The *Triton*'s reactor is regulated by the insertion of control rods made of hafnium, a metal which has a high neutron-absorption characteristic. When the control rods are inserted, the hafnium absorbs a large portion of neutrons which slows down the reaction. It should be noted that the control rods do not stop the reaction, but only regulate it. On board the *Triton*, for example, the reaction is never stopped now that it has been started. The *Nautilus* steamed more than 60,000 miles before the uranium-235 fuel pellet—no larger than a golf ball—had sufficiently diminished in power to necessitate refueling.

### NUCLEAR FABRICATION

In the installation of the *Triton*'s two reactors and the fabrication of her nuclear-piping systems, close control of every element of fabrication was necessary. All piping systems in her reactor compartments do not carry radioactive material; however, much of the auxiliary piping and components are within close proximity of radioactivity. Obviously, if such equipment fails in service, the job of repairing is extremely difficult because of the time required for radiation to decrease to a tolerable level. The best maintenance for a nuclear system is preventive maintenance. It is essential that the original installation is fabricated by highly skilled personnel and that their work be checked with the most advanced quality-control methods.

As was true of the *Triton*'s hull material, the first step in the fabrication of her reactor compartment was inspection of piping as it was received. Figure 15 shows a section of small-diameter pipe being internally examined by a boroscope which, by a series of lights and mirrors, allows the bore to be examined for tears and finish requirements. The other inspector is examining the outside of the pipe by the fluorescent-light method for laps or tears. A complete record of each piece of pipe is maintained.

After passing receiving inspection and bending in the Pipe Shop, the pipe went to the "clean room." All pipe that was to become part of the reactor system was fabricated under surgically clean conditions. Dirt- and scale-free pipe, such as used in commercial high-pressure steam systems, is considered as "grade C" cleanliness. Reactor pipe is "grade

**Figure 15. Small-diameter nuclear piping being inspected for internal and external surface conditions. To the right is TRITON's large-diameter primary-coolant piping.**

**Figure 16. Prior to assembly all nuclear pipe went through a rigid cleaning cycle.**

A." Figure 16 shows this same pipe as it goes through a cleaning cycle of trisodium phosphate and an alkaline cleaner with a wetting agent. This was followed by a tap water rinse and finally a demineralized water rinse.

From here the pipe went to the "clean welding area." All personnel in this area must wear clean uniforms and footwear. Every piece of equipment used by the mechanic is continually cleaned. Vacuum cleaners are used twice a day, even on the walls. The building is so constructed that a slight pressure can be maintained inside at all times to insure that no dust can come in from the outside.

### CONSUMABLE-INSERT WELDING

The *Triton*'s reactor piping system is austenitic stainless steel. The conventional method for butt welding pipe is to utilize a backing ring placed at the inside diameter of the pipe ends. This ring is used to support the initial, or root-pass, weld while it is molten. For nuclear work, this type of configuration is undesirable because of the inherent crevice between the backing ring and pipe where radioactive material can become entrapped. If maintenance work is necessary, even though the system is flushed, a radioactive "hot spot" would remain between pipe and backing ring. Also, as is true of any pipe welding, there is the possibility of weld cracks emanating from the notch effect created at the mating of backing ring and pipe ends. An extensive program was undertaken to develop a welding method for depositing this critical root pass so that the backing ring could be eliminated [2]. This technique is known in the welding industry as the consumable-insert method for root-pass welding [3].

Figure 17 shows a comparison of the two methods. Consumable-insert welding is a method whereby a

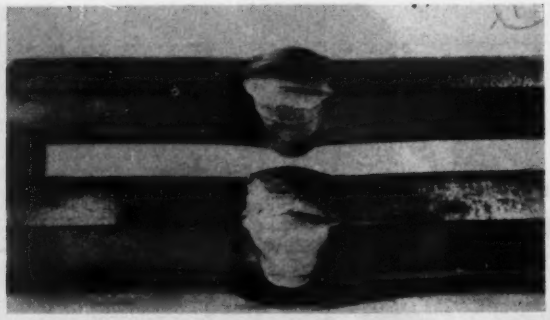

**Figure 17. The lower pipe weld was made by the conventional backing-ring method. Because of the crevice between the backing ring and pipe ID, this weld is not acceptable for nuclear service. The other weld, which eliminates the crevice, was deposited by the consumable-insert method.**

material of proper composition and cross section is preplaced between pipe ends. The consumable insert and the pipe ends are then completely fused at the root of the weld bevel by the inert-gas tungsten-arc process. The resulting weld nugget is smooth and uniform and without the troublesome crevice on the pipe ID. An advantageous feature of this particular method of no-backing-ring welding is that gravity has little, if any, effect upon the molten puddle and, consequently, the method does not rely on pressure inside the pipe to support the molten puddle.

Figure 18 is the joint geometry used for austenitic stainless steel and certain other alloys. After root-pass welding, the joint is finish welded by the conventional manual metal-arc process.

The *Triton*'s specification allowed pipe sizes 1 inch and below to be welded as a socket welded system. One requirement for socket welding is that a space of 1/32 to 1/16 inches be left between the

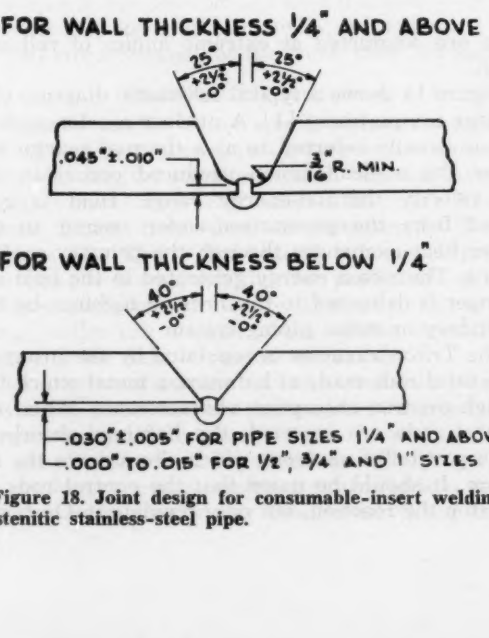


**Figure 18. Joint design for consumable-insert welding of austenitic stainless-steel pipe.**

pipe end and the bottom of the socket fitting to allow for movement of the parts due to weld shrinkage. This requirement is particularly important in austenitic stainless-steel systems because of the high coefficient of thermal expansion. Experience has shown that without this space, cracking will occur through the throat of the weld upon cooling. But, on the other hand, this built-in crevice is an ideal radioactive "hot spot." By consumable-insert welding of these systems, not only were the cracking possibility and the "hot-spot" condition eliminated but, on straight runs, one weld and the cost of the socket coupling was also eliminated. Figure 19 graphically shows a comparison of these two methods of pipe welding.

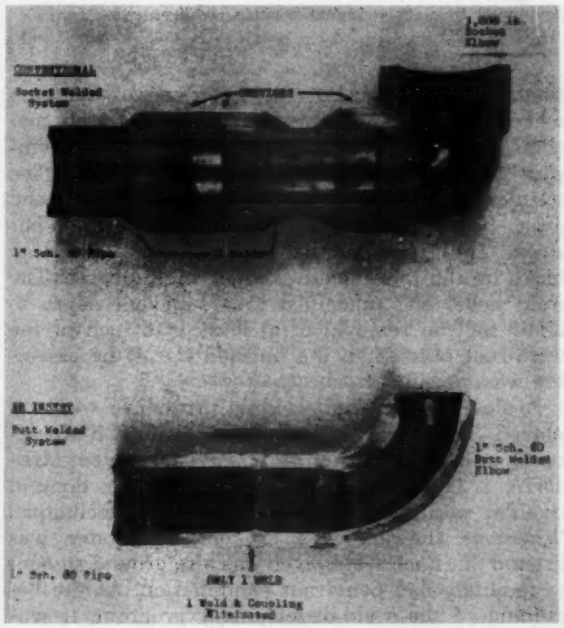

**Figure 19. In small-diameter nuclear piping, consumable-insert welding also reduced the weight and cost of fabrication.**

NUCLEAR INSPECTION

After consumable-insert welding the root pass, the weld bead was examined by the liquid-penetrant method (Figure 20). Here, the inspector is applying the red-dye penetrant. After being allowed to penetrate into any small fissures that may be in the weld, the dye is cleaned off, and a white powder is dusted on. This powder has an affinity for the red dye, drawing it out to the surface. The resulting fine red lines which may appear on the white background denote cracks. At this point, the weld was completed by the manual metal-arc process (Figure 21).

Final inspection consisted of radiographic exam-

**Figure 20. Root-pass welding was followed by a dye-penetrant inspection.**

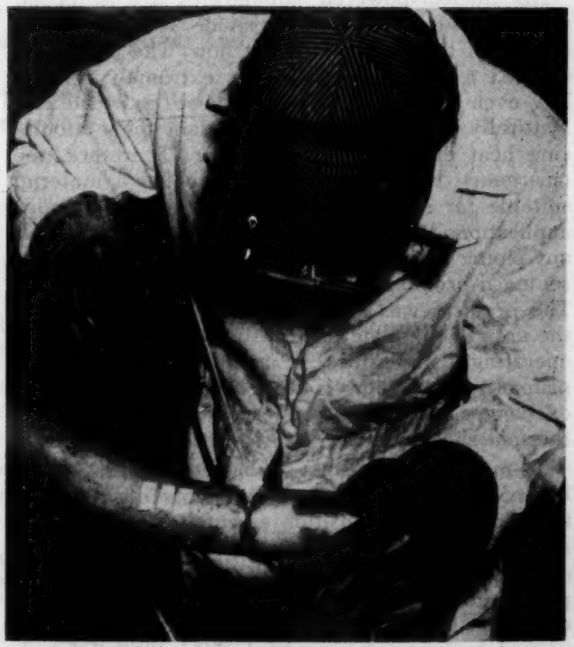

**Figure 21. Welder working in the "clean area" completes the weld.**

ination and a second dye-penetrant inspection. Figure 22 shows a typical submarine reactor-piping complex. The paper tapes on each side of the welds denote the various stages of inspection that have been completed. It can be seen that there is very little straight pipe in this arrangement of main-coolant pumps and check valves. Many fittings are at odd angles which means special forgings.

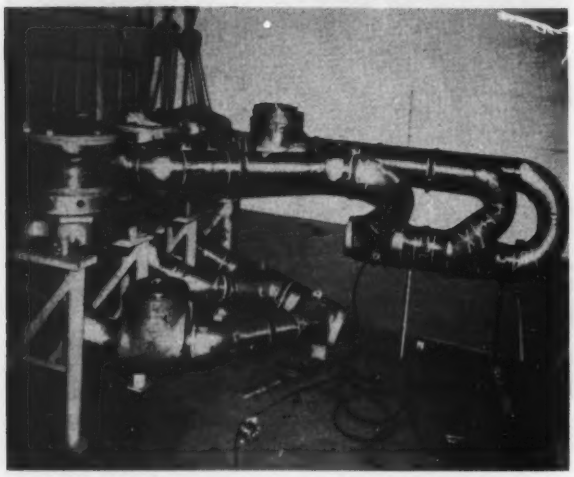

**Figure 22. Because of space requirements, many specially forged fittings were required.**

### BIMETALLIC WELDING

All nuclear-powered submarines are equipped with heat exchangers to provide for emergency cooling of the primary-coolant flow. The possibility of such a condition existing is extremely remote, but even the unexpected must be provided for. Naturally, the most available coolant for a submarine heat exchanger is sea water. Therefore, the emergency heat exchanger must be of a material suitable for sea-water service. For this particular application, Monel was chosen. Since primary-coolant piping is austenitic stainless steel, joining presented a problem because of the dissimilar metals. The problem was compounded by the fact that in the area of the material transition, though the non-operating temperature is ambient, when the hot primary-coolant flow is diverted through the heat exchanger at near reactor temperature, an extreme thermal shock occurs.

To meet these arduous service conditions, a number of nuclear-equipment fabricators made Monel to stainless-steel transition assemblies for thermal-shock testing. Some were mechanical joints, while others were mechanical with seal welds. The approach used at the author's plant was an all-welded assembly. Figure 23 shows the configuration which proved to be most successful. A section of 5-inch diameter annealed bar stock was used for the Monel

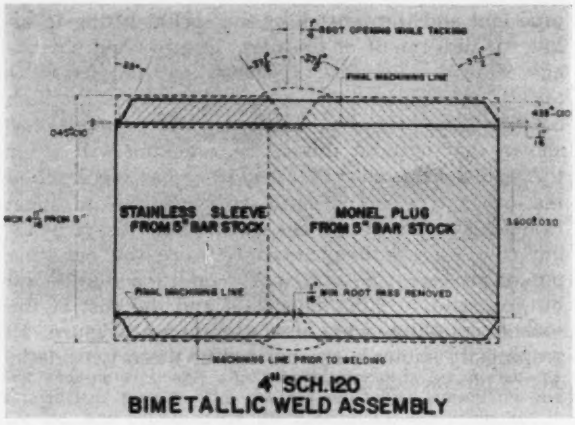


**Figure 23. A special method for bimetallic welding was developed to meet stringent service requirements.**

plug. Prior to welding, the right end of the plug was square cut and the left end was rough machined with a 37½-degree weld bevel and an extension to fit into the stainless-steel sleeve. The stainless-steel sleeve was square cut on the left end after being rough machined from annealed-bar stock. The right end had a 37½-degree bevel to make up the total included angle of 75 degree. The weld bevel was machined to a sufficient depth to allow for the removal of at least 1/16 inch of the weld-root pass when the finished ID of the assembly was machined.

A closely controlled welding procedure was employed. The electrodes used were Ni-Cr-Cb-Mo according to specification MIL-E-17496, Type MIL-4N1A, 3/32 inch diameter. All welding was done in the flat position using a stringer-bead technique. Wherever the arc was broken, the crater was ground off. Each weld layer was also ground smooth to facilitate dye penetrant examination. At the beginning of the weld-development program, it was believed that if the fit between the Monel plug extension and the ID of the stainless-steel sleeve was kept to a maximum of 0.005 inch at a point, the propensity for cracking of the root pass would be reduced. In practice, this was not the case. It was felt that due to the differential in thermal-expansion coefficients of the materials, the two pieces tended to seize at the mating surfaces, and the induced restraint caused root-pass cracking. By increasing the fit-up to 0.010 to 0.015 inch, the pieces evidently were able to move during root-pass welding, and cracking was reduced.

After radiographic acceptance, the assembly was finish-machined to the dimensions shown. Final acceptance was based on a hot-dye-penetrant examination and hydrostatic testing.

The all-welded bimetallic assemblies proved superior after hundreds of thermal shocks and the additional test requirement of inducing mechanical

stresses and simultaneously imposing mechanical shock blows.

Subsequent to thermal- and mechanical-shock testing, procedure-qualification test welds were sectioned for metallographic and mechanical testing. Metallographic examination of both unetched and etched specimens revealed no cracks, fissures or other defects. Mechanical testing by root and face bends was satisfactory. All tensile specimens exhibited ductile failures in the Monel base material.

Welds fabricated to the above procedure are now used on all nuclear-powered submarines.

### References

[1] Rush, C. W., Chambliss, W. C., and Gimpel, H. J., *The Complete Book of Submarines.*

[2] Risch, T. A., and Dohna, A. E., "Consumable Insert Method of Root Pass Welding," *The Welding Journal,* 33 (7), 670-679 (1954).

[3] U. S. Patent 2792490, May 14, 1958. Issued to General Dynamics Corp.

The De Laval Ljungstrom Turbine Company, of Stockholm-Nacka, Sweden, have fitted a new type of ballast pump in the tanker ***Texaco Iowa***, built by Kockums Mekaniska Verkstads A/B, of Milmö, for the Texas Company, New York, N. Y. It is a vertical-spindle centrifugal pump driven by a single water-turbine wheel, and will deliver 925 gpm at 1500 rpm. The pressure water to drive the turbine is supplied by a Butterworth pump delivering 360 gpm at 170 psig. The unit is suspended submerged about three ft from the bottom of the tank by means of its own piping. The turbine wheel and the pump impeller are mounted on a common shaft and enclosed in a bronze casing. The bearings are water-lubricated by driving water tapped off the main delivery pipe through a bypass in which are a settling tank and a gravity dirt trap. Six months in service have shown that the new pump has a capacity about double that of a normal water ejector used in conjunction with a Butterworth pump and under similar operating conditions.

—From MECHANICAL ENGINEERING
November 1960

The average research expenditure for all U. S. industries is 2% of gross sales and in 1940 shipbuilding was tied for last—with the bakery and cane industries—in the amount spent on research, which was about 1/10th of 1% of sales and "I suspect today's relative rankings are not far different." Such was the opinion expressed by Prof. Harry Benford, of the University of Michigan's Department of Naval Architecture & Marine Engineering, in a recent talk at the Chesapeake and Hampton Roads section of the Society of Naval Architects & Marine Engineers. Among fields best suited for research he indicated inland rivers and the Great Lakes—a new model basin and propeller tunnel suitable to the needs of inland rivers, and for the Great Lakes new designs taking into consideration the possibility of a greatly enlarged lock at the Soo, maneuverability in restricted waters, extreme hull proportions, collision prevention needs and the possibility of year-round ice-free navigation.

—From MARINE JOURNAL
October 1960

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# *MARINE ENGINEERING NOTES FROM THE SOVIET PRESS*

**THE AUTHOR**

***enlisted in the Navy in 1931, and served continuously until his retirement. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institution. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He was recently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service and retired after 29 years of active duty. His last duty station was in the Office of the Chief of Naval Operations. Is now engaged in consulting and independent research on Soviet affairs.***

## RESEARCH SUBMARINE *Severyanka*

LATE IN NOVEMBER the Soviet submarine *Severyanka* departed from Murmansk on her sixth voyage into the Atlantic, this time to the north Atlantic in the area between Iceland and the Faroe Islands where fishing fleets from Murmansk, Kaliningrad and Latvia are hunting sardines. She was to rendezvous with the scientific-research ship *Akademik Berg* and operate for from 20 to 25 days, covering some 4,000 miles of ocean.

The reason for the voyage is an interesting one. Both the Polar and the Baltic institutes have, in recent years, conducted various experiments connected with deep sea fishing and oceanography in an effort to determine the reason or reasons why medium sized fishing trawlers have been experiencing difficulties with their trawls. Too, catches brought up by these trawls have been poor, according to reports. Among the questions posed were those concerned with trawling speeds, the spilling of the fish from the trawls, etc. Since the answers could be found only by the use of underwater investigation it was decided to convert a submarine for use by the fishing institutes, and *Severyanka* is the result. In Soviet terminology the boat is termed a "new and powerful" weapon.

In any case, three voyages ago *Severyanka* demonstrated her ability to observe, and film, trawling at various depths in the Barents Sea. This time the operation of the trawl will be observed with the aid of "photo eyes" fastened to the trawl. These devices are described as automatic underwater cameras with programmed direction, designed by the All-Union Scientific-Research Institute for Marine Fishing and Oceanography. *Akademik Berg*, basically a medium-sized trawler, will test newly designed trawls said to have less resistance than older types and permitting the trawler to develop more speed. It is antici-

**The research submarine *Severyanka* from a photograph printed in November 1960, shown prior to going to sea on sixth voyage.**

pated that direct observations of the operation of these trawls by *Severyanka* will determine the reasons for failure of the trawls to perform as anticipated and permit the designers to make changes as required.

Along with these tests will be tests and observations of the hydro-optical parameters of the waters in the Sea of Norway. Light penetration of the water depths will also be recorded, using new, strong searchlights fitted prior to the departure of the submarine, as well as new underwater lights which will require testing.

### *Mir* and *Druzhba*—NEW TANKERS

Peace and Friendship—obvious names for the propaganda-minded Soviet officials who must assign names to new ships—are the translations for the new tankers *Mir* and *Druzhba* now flying the Hammer and Sickle. Both were built in Japan. An Associated Press dispatch, appearing in the New York *Times* on 3 November 1960, noted that a Soviet purchasing mission was near agreement with Japanese concerns on three, 35,000-ton tankers, to be deducted from five smaller vessels already listed for purchase under a Soviet-Japanese trade agreement.

Later in the month Soviet press reports noted the purchase of the tanker *Mir*, as well as her arrival in Vladivostok to make preparations for a voyage to the Black Sea. *Mir*, and her sister *Druzhba*, displace almost 51,000 tons and can carry over 37,000 tons of petroleum products. Both are equipped with steam turbines developing 17,600-hp and can make about 17-knots. Some 700-feet long and 93-feet in the beam, they are well in excess of the size of the *Pekin*-class which have been built, and are building in the Soviet Union.

*Mir* departed Vladivostok on 27 November and arrived in Odessa, presumably in ballast, on 23 December and proceeded to Vladivostok to prepare for the voyage to the Black Sea in turn.

At about the same time, on 20 December, one of the *Kazbek*-class tankers, *Yegoryevsk*, proceeding from Hamburg to the Black Sea in ballast, blew up, forcing the crew to abandon ship. Placed in service in 1958, *Yegoryevsk* carried a 43-man crew under Captain M. V. Fomin, formerly in command of *Leningrad*, second of the *Kazbek*-class to be built, and an experienced mariner.

Casualties appear to have been light, thanks to timely rescue work on the part of the British tanker *Clyde Sargent*. The hulk was taken in tow and, after considerable difficulty was finally towed into the French port of St. Nazaire on the night of 30-31 December. Ultimate fate of the tanker, which appears to have suffered heavy damage, is unknown.

### NEW CONSTRUCTION

Among the new ships which were added to the Soviet merchant marine in the past quarter were survey ships *Sergey Vavilov* and *Petr Lebedev*. The two motorships, products of the A. A. Zhdanov Shipyard in Leningrad are said to be "true floating laboratories, equipped with the latest equipments for conducting hydrological, hydro-biological, oceanographic, and other research." The addition of these two ships brought to seven the number of survey ships which were actually, and actively, engaged in studying the seas and oceans in the last quarter of the year.

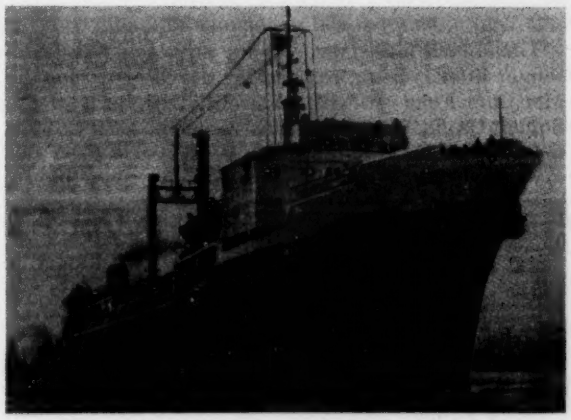
A fourth *Pekin*-class tanker, *Praga*, was reported on the ways in the Admiralty Shipyard, indicating that the practise of building "super" tankers named for the capitals of the captive nations continues.

Late in November *Pavlin Vinogradov*, first of a series of timber carriers of a new design, left the Baltic Shipyard *imeni* Sergo Ordzhonikidzye for underway trials. Displacement of the ship is 10,000 tons and this series differs from previous ones by the placement of the superstructure aft. This type of design is said to provide for greater capacity and at least 5,000-tons of various types of timber can be stowed in the holds and on deck. In addition, this is the first Soviet-built cargo carrier to be equipped with a gas turbine installation with free-piston generators. The installation is rated at 4,000-hp and is said to be operated on the "cheapest grades of fuel."

The fishing fleets continue to add new ships to their rosters. *Volzhsk*, latest of the *Aktyubinsk*-class refrigerators, was assigned to the Kaliningrad Fishing Flotilla and is said to be able to process 50 tons of fish a day. *Ulis* and *Uzhgorod*, products of the

"Leninskaya Kuznitsa" Shipyard in Kiev, were delivered to Kherson on pontoons and then were sent out on underway trials in the Black Sea. The two trawlers were then sent around to the Far East and will operate out of the port of Nevelsk for the Sakhalin *Sovnarkhoz*. Personnel of the Kaliningrad Maritime Agency for Ship Transfers, a ferry organization, took the two ships around to their destination.

*Andrey Zakharov* (see cut) is a product of the Admiralty Shipyard, and is the first of a series of floating fish cannery-factory ships displacing 16,000-tons, the same displacement as the *Kazbek*-class tanker. Ultimate destination is the Far East and a sister ship is reported on the ways in the shipyard.



**The new floating fish cannery-factory ship *Andrey Zakharov*, shown leaving the Admiralty Shipyard, Leningrad. Ultimate destination is the Far East.**

Listed below are the merchant ships, auxiliaries and special craft delivered or under construction and first noted in the past three months:

| *Name* | *Where Built* | *Type* | *GRT* |
|---|---|---|---|
| *Adler*, m/v | Holland | Tanker[1] | |
| *Akstafa*, m/v | USSR | Cotton-Timber[2] | 3000 |
| *Alma Ata*, m/v* | Bulgaria | Tanker | 3000 |
| *Amata*, m/v | East Germany | Cargo | 3358 |
| *Aralsor*, m/v[5] | USSR | Fish Factory | |
| *Aransk*, m/v | | Cargo | |
| *Dipkun*, m/v[5] | USSR | Fish Factory | |
| *Dobrush*, m/v | East Germany | Cargo[3] | |
| *Dolmatovo*, m/v* | East Germany | Cargo[3] | |
| *Druzhba*, s/s | Japan | Tanker[4] | |
| *Dubno*, m/v | East Germany | Cargo[3] | |
| *Dubossaryi*, m/v* | East Germany | Cargo[3] | |
| *Elva*, m/v | | Cargo | |
| *Firyuza*, m/v | Finland | Cargo | 1870 |
| *Fedya Gubanov*[5] | | | |
| *Geokchay*, m/v[5] | USSR | Grain-Timber | 3000 |
| *Gnevnyiy*, d/e | USSR | Whale Catcher | |
| *Gradiyent*, m/v | USSR | Survey | |
| *Ispolnitelnyiy*, m/v | | Tug | |
| *Khiyumaa*, m/v | Hungary | Cargo | |
| *Kura*, m/v | West Germany | Refrigerator | 4410 |
| *Liyepaya*, m/v | USSR | Tanker | 8229 |
| *Makhtra*, m/v | East Germany | Cargo | |
| *Mir*, s/s | Japan | Tanker[4] | |
| *Ordzhonikidzye*[5] | | Fish Transporter | |
| *Praga*, s/s* | USSR | Tanker[6] | |
| *Pavel Frolov*, d/e | USSR | Whale Catcher | |
| *Tartu*, m/v | Hungary | Cargo | 1194 |
| *Tiraspol* | | Tug[7] | |
| *Ulis*, m/v | USSR | Trawler | |
| *Uzhgorod*, m/v | USSR | Trawler | |
| *Volzhsk*, d/e | USSR | Refrigerator | 5217 |
| *Yasnogorsk*, m/v | Poland | Cargo | 9935 |
| *Yeysk* | | Tug[8] | |
| *Zharkiy*, d/e | USSR | Whale Catcher | |
| *Zheleznyakov* | | Tug[9] | |

* Under construction
1. 32,000 displacement tons
2. Fifth of this series
3. 8,000 tons cargo capacity
4. 37,000 tons cargo capacity
5. Caspian Sea vessel
6. *Pekin*-class
7. Former naval tug *RChB-28*, converted to civilian use on the Danube River
8. Former naval tug *Bug-143*, converted to civilian use on the Danube River
9. Former river monitor, under conversion for civilian use on the Danube Rive in Izmail

### OCEAN-GOING PASSENGER LINER

The sketch plan (see cut) for an ocean-going passenger liner is being readied for the Ministry for the Maritime Fleet. It will, apparently, be built in the Soviet Union, the first such vessel of this size attempted by Soviet shipbuilding experts.

**Artist's conception of a proposed Soviet passenger liner for the tourist trade.**

Although details are meager it is said that the steam-turbine propelled ship will be some 740-feet in length and will be equipped with engines rated at 75,000-horsepower. Initially suggested speed is 25-knots, with the possibility that this will be increased to 28-knots.

As has been pointed out, Soviet operators feel that, for their purpose, separation of a passenger ship into several classes results in lost revenue as the more costly space remains idle for varying periods of time, depending on the run. Hence, the proposed ship will be a one-class ship, with the plans calling for 350 two-place cabins and additional cabins to provide for carrying about 1,000 passengers.

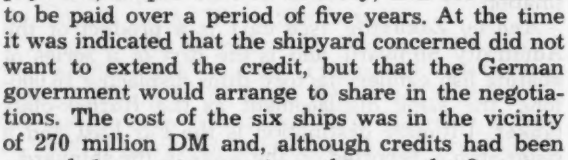
Two swimming pools are stipulated features of the ship, one in the open air, the other a covered one. This feature would appear to be in line with the statement that the new ship, when built, will be used exclusively for the tourist trade.

This, in turn, dovetails with previously reported expansionist policies using merchant ships as the medium in the course of expanding trade ties. The usual practise is to move "tourists," "observers," or "technicians," the name used varying with the approach for a particular country, into the country on the heels of trade or other agreements.

Recent classes of passenger ships, some of which are in use on the Baltic run out of Leningrad, have been built in East Germany and in the Soviet Union, but these have been relatively small ships, 400-feet in length, for example, and hardly in keeping with the prestige the Soviet Union now feels that it enjoys in the maritime world. It will be recalled that a twenty-year old passenger liner, *Baltika*, built in Holland, had to be used to bring Mr. Khrushchev to the United States last fall. Or perhaps the reason for the proposed new passenger liner lies in the fact that Soviet leaders are so intent on proving that they can do things better than mere capitalists that they have decided to try their collective hands at this trickiest of merchant ship types.

While this writer tends towards the belief that the liner may be built in the Soviet Union, it is recalled that two years ago negotiations were underway between the Soviet Union and the Blohm and Voss Shipyard on the building of six passenger ships, each of some 13,000 GRT. It was reported that negotiations were in the stage of arranging payment conditions, along the lines of a 10 per cent down payment, 30 per cent on delivery, and the balance to be paid over a period of five years. At the time it was indicated that the shipyard concerned did not want to extend the credit, but that the German government would arrange to share in the negotiations. The cost of the six ships was in the vicinity of 270 million DM and, although credits had been extended to various nations, this was the first time that such credits had gone to a Communist country. Even so, the period had not been in excess of four years.

There is nothing to suggest that this deal was consummated, but the possibility cannot be overlooked that yet additional assistance will be forthcoming, from Western yards, this time in the form of tourist liners flying the Soviet flag.



**Profile of a new class of passenger ship under construction in Stalingrad for use on the Caspian Sea.**

Yet another type of passenger ship is under construction, this one for use on the Caspian Sea to carry the oil workers from Baku to the oil drilling areas in the sea, and return. The first is under construction in the Stalingrad Shipyard to class R 4/1 S (Casp.M.) of the Maritime Register of the USSR, taking into account the fact that the ship will have to embark, and disembark, passengers at places and in areas which are not sheltered from the action of the waves. Characteristics include:

| | |
|---|---|
| Length overall, feet | 270 |
| Length between perpendiculars, feet | 252 |
| Beam, greatest, feet | 46 |
| Height of side to upper deck, feet | 26.5 |
| Full displacement, tons | 1875 |
| Draft at full displacement, feet | 12 |
| Speed, knots | 16.5 |
| Cruising radius, miles | 650 |
| Passenger capacity | 600 |
| Crew | 46 |

### RIVER SHIPS

East Germany continues to deliver 3-decked passenger motorships for use in the Volga River, among others. The three most recent deliveries are *Kozma Minin, Sergo Ordzhonikidzye* and *Stephan Razin*, all of which will winter in Arkhangelsk and, at high

water this spring will proceed via the inland waterways to the Volga River for service.

A river passenger ship designed to carry 172 passengers, named *VTU-301,* is said to be the largest of the ships operating on the Kuban River. It was built in the Velikiy Ustyug Shipyard and found its way to the Kuban via the Sheksna, Sukhona, Volga, and Don rivers and the Sea of Azov, finally arriving in Krasnodar several months after departure from the building yard.

The Batumi Shipyard is building a group of plastic runabouts and will, this year, start the production of small river craft known as "trolley-bus types." The hulls and superstructures of these craft will also be made of plastics.

The shipyard named for the 40th anniversary of the October revolution, Gorkiy, is finishing up the work on a catamaran. The steel hulls are 246-feet long and the ship will have a capacity for 600-tons of cargo. Each hull will house an engine rated at 1080-hp and remote controls are mounted on the bridge. Each hull has its own propeller and rudder and deck machinery is electrically operated. An 11-man crew took the ship out on a 60 mile test run on the Volga River late in October and an average speed of some 15-knots was obtained. Final trials will be held on the Gorkiy Reservoir.

In addition to the work being done with plastics in Batumi, the *Imeni* Kalinin Shipyard, builder, in 1958, of the first of the plastic passenger cutters, is continuing its work with plastics. Recently the Leningrad Institute for Water Transportation, working with the shipyard, completed the development of use of a vacuum method of molding the hulls. Use of the new method is said to increase production, while cutting costs. Plastics are also in use for the manufacture of navigation buoys.

Designers in the Stalingrad Shipyard on the Volga River have worked out a technical project and the working plans for a river tanker with a cargo capacity of 5,000 tons which will be the largest tanker on the river. The design is suitable for use only on the Greater Volga, however, and there is no indication that this tanker will be in competition with the *Oleg Koshevoy*-class which operates on the Volga and the Caspian Sea as well. These tankers will, it is presumed, supplement the 60 so-called "composite tankers," a permanently teamed tug and oil barge, now in use in the Volga Tanker Steamship Line. Twelve of these latter were in constant operation in 1960 carrying gasoline on a run which touched Kuybyishev, Gorkiy, Yaroslavl and Ryibinsk. The tug serves as the pusher and the use of this pushing method, it is claimed, helped to speed up delivery of Category I cargoes 20 per cent.

There is continuing evidence that river ships are becoming more venturesome. Most recent note was that of the passage of *Vinnitsa*, a 2000-ton capacity motorship, carrying a cargo of lumber from Ryibinsk directly to Taganrog on the Gulf of Taganrog.

"Leninskaya Kuznitsa" Shipyard has completed the development of the sketch plan for a new type of passenger ship designed to operate on the section of the Dnepr River from Kiev to the mouth and on across the Black Sea to the port of Odessa, further indication of the planned use of river ships for partial coastal use as well.

Engineers assigned to the Central Technical-Design Bureau of the Ministry for the River Fleet have collaborated with the Ship Theory Department of the Institute for Water Transportation on the design of a shallow draft, twin-hulled motorship using hydrofoils. Chief Engineer of the project is S. B. Shur who says the original plans had called for a catamaran with water jet propellers, that the twin-hull design improves stability and that the lengthened hull form will enable the craft to get up on the foils with a lesser expenditure of power. Two types are in design—one capable of accomodating 100 passengers, the other 50. The cruising radius will be on the order of 300 miles and speeds will be around 25-28 knots. Draft will not be in excess 2½ feet. Automatic controls will permit cutting the crew to four.

The Stalingrad Shipyard has built a 300-hp ferry which can carry automobiles and passengers on the reservoirs and on the lower reaches of the big rivers, such as the Volga. Some of the ferry's characteristics are:

| | |
|---|---|
| Length overall | 120 feet |
| Beam, greatest | 39 feet |
| Draft, empty | 4.7 feet |
| Draft, full load | 5.8 feet |
| Displacement, empty | 138 tons |

Capacity: 8 ZIL-150 automobiles and 100 passengers

### NEW RIVER TANKER

The first of a series of 2800-ton capacity river tankers, built in the "Krasnoye Sormovo" Shipyard in Gorkiy, was reported in use in November. Serial production is to get underway on the class, which is all-welded, has but one deck and double bottoms under the cargo tanks, and is strengthened for operation in limited ice conditions. It can carry any petroleum products in classes I, II and III but no heating coils have been installed so that some limitation is imposed. Characteristics include:

| | |
|---|---|
| Length overall | 358 feet |
| Beam, greatest | 44 feet |
| Height of side, calculated | 15.8 feet |
| Height, overall | 41.5 feet |
| Draft, in ballast | 5.3 feet |
| Draft, mean, loaded | 10.5 feet |
| Propulsion, 2 x 500 | 1000 horsepower |
| Speed, deep water, knots | |
| Empty | 11 |
| Loaded | 10 |
| Crew | 20 |

Design of the tanker is based on the design used for the cargo motorship *Shestaya Pytiletka* of Project 576, but with a hull which is some 53 feet longer. The engines are those used in the Project 576, the

R6DV-148, with remote controls installed in the wheelhouse.

Defects which were noted included lack of a catwalk from the stern superstructure to the forecastle, lack of cargo pumps, lack of complete automation, and the fact that, even with a small swell running the tanker buries her bow too deeply when loaded.

Recommendations have been made concerning the elimination of these defects in succeeding ships of the class.

### *Belorussiya* SCRAPPED

After 42 years of service, the US-built (1918) cargo ship *Belorussiya* is being scrapped in Odessa. Her career appears to have been a distinguished one, it being noted that she had been in repair but three times in her last 13 years of operations. Captain Solovyev had been in command since 1947 and took the ship into the Odessa Ship Repair Yard for the breakup. Everything on board of value, or use, is being placed in storage. The crew is to be reassigned to a "new, big ship."

### HYDROFOILS

Latest of the hydrofoil classes, *Sputnik*, is under construction in the experimental shop of the "Krasnoye Sormovo" Shipyard. Late in November the hull plating was partly in place and machinery foundations for the four engines were completed. *Sputnik* is to be equipped with four propellers and is designed for a speed of some 50-knots. Space is provided for 300 passengers and delivery, for use on the Volga River, is set for the 1961 river season.

The Chief Constructor for Hydrofoils, Engineer S. V. Moiseyev, claims that the yard will soon start the construction of the first hydrofoil with a plastic hull and superstructure. Apparently an experimental model, this particular craft is built to carry six people. In 1962 plans call for the building of 30-passenger types which will operate at speeds up to 60-knots on the small rivers where shallow draft is a must in design.

Of the *Sputniks* under construction or to be built, one will be equipped, sometime in 1963, with a gas turbine installation which will enable the ship to develop a speed in excess of 60-knots. Soviet nomenclature for hydrofoils is such that all ships of a particular class carry the same name; i.e., *Raketa*-class hydrofoils are operating in the Volga basin, as well as on the Yenisey River and other rivers, yet all are named the same—simply *Raketa*. Of the *Sputniks* it appears that two are under construction at present but future plans call for mass production not only of ships as large as this, but of cutters as well.

One such is *Belarus*, a 25-30 place passenger hydrofoil of a new type, the construction of which is to start this year in the Gomel Repair-Operations Base.

Results obtained during acceptance tests conducted for *Meteor* (see the "Journal," November, 1960, p. 680) were mixed. According to the Chairman of the Commission assigned to conduct the tests, Mndoyan, the experimental model demonstrated satisfactory underway and maneuverability qualities and its mechanical operation was such as to permit acceptance. However, while operational speed of some 40-knots was obtained, ventilation was said to be very poor. Air supply forward was only 80 percent of that required by the standards set for underway operation, and only 50 percent of required while at anchor. In addition the after compartment was very noisy and hull vibration was especially bad in this area. Buffet and refrigerator space was deemed inadequate to service the number of passengers which will be carried. No thought had been given to stowage of life-saving equipment, outer garments of passengers, etc. Despite these defects the lead model of what is known as Project 342 was accepted, but the building yard, "Krasnoye Sormovo" was told to eliminate the defects and to start serial production of the hydrofoil in two modifications: one to be used for transit lines and carrying 130 passengers; the other to be used on local, or suburban, lines and carrying 150 passengers.

### WINTER SHIP REPAIR—1960/61

Some idea of the scope of the repair program now underway in the Soviet Union on its river ships may be seen from the following approved plan. The chief objectives of the program are modernization and improvement in the quality of the repair work done.

1400 ships are to be modernized. 136 motorships and 42 dredgers are to be equipped with remote engine controls. 50 steamships are to be converted to diesels, 156 are to be converted from coal to oil burners. Mechanized anchor windlasses are to be installed on 291 barges. Automatic coupling devices are due for installation on 107 tugs and 199 barges. 7 motorships and 5 steamers will be fully automated and gas-turbine supercharging will be installed on 19 motorships. 89 steamers are to be refitted so that operating steam pressures and temperatures will be higher and 108 steamers will have automatic feed water regulators installed, 50 will have automatic steam pressure systems provided. Hatches will be widened on 35 steel barges of Project 425 and 26 tugs will get towing winches.

Deadline for all repair work is the opening of the 1961 season.

### BRYANSK DIESEL WORKS

Despite the fact that most of the work on the prototype engine under construction in the Bryansk Diesel Works is completed (see cut), no firm delivery date has been set for the engine. The problems which have plagued the Works continue and it now appears that production of some of the vital parts, such as gear pumps, has not yet begun.

According to information emanating from the Works, the engine frame is 14-meters long; the crank shaft weighs 80-tons. It is pointed out that the shop

**The first 9,000 horsepower diesel engine produced by the Bryansk Machinebuilding Works.**

in use for assembly of the engine was formerly used as a turbine assembly shop and, although well-equipped, was neither designed for, nor is it suitable for, the assembly of diesel engines. No test stand for an engine of this type is available. It is indicated that such a test stand will be installed in the new diesel assembly building, but, as of early October, the building was not yet ready for occupancy. Other shops, part of the overall complex, have been assigned specific roles in the manufacture of parts for the marine engine series. However, the heavy parts sections have experienced high rejection rates for their products and the scrap pile is said to be huge. The foundries, perhaps the most important of all the shops, have had trouble solving the problems they have encountered, with many of the solutions decided upon turning out to be unsatisfactory. Problems have also been encountered in the manufacture, and procurement, of needed tools, with the result that finishing of some of the parts needed for the engine has been held up.

Representatives of the Works have warned that, since the production schedule for 1961 is fixed, or so it would appear, and because conditions are not improving, progress will be worse than it had been in 1960. The implication, assuming that ships will have to wait for engines, is obvious. The bottleneck is said to be unsatisfactory cooperation of suppliers with the builders. Work on the assembly of the second engine could not be started in 1960 because of a lack of sheet steel Mark 15G, on order with the Magnitogorsk Metallurgical Combine. It seems that the required grades of steel had not, in fact, been received for the first engine. Far less than half of the required parts were received, with the Ural Compressor Plant, the *imeni* Kalinin Pumps Works in Moscow, and the Shchelkovskiy Pump Works said to have made a start in organizing the production of such complicated parts as compressors, cooling and fresh water pumps, and lubricators, late in 1960. Only 21 of 112 lathes and machine tools ordered had been delivered late in the year, with the result that operations involving the use of such tools were said to be lagging badly.

The complaints of the engine builders appear to have been heard, at least to the extent that plans were advanced for increasing the number of people assigned to the Design Bureau in the Works by 50 before the beginning of 1961. Incorporated in the new building is a so-called Experimental Shop which will be equipped with special laboratories and individual assembly-test stands. This Shop will be charged with doing the scientific and research work required in the course of building the engines. This increase in personnel and facilities, as well as a number of other measures which were not spelled out, is to result in speeded up production.

Complicating the picture was the statement that, on 19 November, the assembly of the first of the marine diesels was completed. Theoretically, at least, a ship equipped with one of the Bryansk diesels will cost 1,300,000 rubles a year less to operate than a comparable (9,000-horsepower) steam turbine propelled ship. This report also stated that the assembly of the second engine was to have been completed by 15 December and that, in January of this year the serial production of the marine engines would get underway.

And to add to the confusion, in mid-December, at a time when, as was noted above, the assembly of the second engine was to have been completed, it was noted that, although the first engine was considered assembled, it was held up for lack of piping, among other accessories. It seems that the Works had been waiting for four months for 145 tons of steel needed for the test stand exhaust trunk, of which only the plate had come in. 300 tons of various sizes of pipe, needed for the fuel and oil lines, had not come in, and, of better than 1,000 tons of steam pipe needed, only one carload had been received. Only eight of 18 special machine tools had come in and only one of 12 pumps ordered for the third quarter of 1960 had arrived and was under test at the time. Gear pumps, mentioned earlier, had not even gone into production.

It will be interesting to see when an engine from this Works will actually be shipped to a building yard for use in a ship. And it is no wonder that the diesel builders say they need help and are worrying about the progress of the 1961 program.

The reasons for Soviet concern over the progress made by Bryansk become clearer when it is recognized that the whaler base *Sovetskaya Ukraina,* built in the Nikolayev area of the Black Sea, is powered by Burmeister-Wain's 74-VTBF-160 supercharged diesel. This propulsion unit is a two-stroke,

crosshead type, single acting, reversible engine utilizing solid fuel injection. It is a six-cylinder engine rated at 7500-ehp and makes 115 rpm. In its non-supercharged version this engine was built in 1939 as a 5520-ehp unit, at 115 rpm, and was installed in the Danish-built tankers *Apsheron* and *Tuapse* in 1952.

The same engine, turbo-supercharged however, and in a 7-cylinder version, is said to be building in one of the Soviet machine building plants for use in the 10,000 ton cargo capacity dry-cargo carriers building in the Soviet shipyards which will carry the engine room aft.

Thus, manufacture of large engines for propulsion use in Soviet-built ships will eliminate a rather basic dependence on Western nations for not only the engines, but the need to acquire spare parts, which has not, in the past, always been easy.

### PROPELLERS

Propeller maintenance, particularly among ships assigned to the Far East and to the Arctic, is unsatisfactory. This is the conclusion of Ye. Peshkov, who is Senior Engineer for Propeller Maintenance in the Far East. It is Peshkov's opinion that propellers cast from ordinary carbon steel have deteriorated in from one to two years after installation because the steel used has been unable to withstand the corrosive effects of sea water.

He further notes that the initial cost of the cast steel propeller is much less than that of a cast brass propeller, but that the period of service is hardly comparable. Too, Soviet experience has been that cast steel propellers require replacement in from two to three years, whereas brass propellers can be used for from 10 to 15 years. But the important fact seems to be that ships fitted with cast steel propellers, after a year of operations with this type of propeller, lose from 10 to 12 per cent of their designed speed because of the extensive blade corrosion which occurs. Accordingly, Peshkov urges that the manufacture of steel propellers be stopped forthwith and that a program be started to replace the steel propellers with either stainless steel or brass.

Since the Seven-Year Plan calls for the addition of high speed ships, the use of the more expensive types of propellers is urged and the plea is based on the fact that they will pay for themselves many times over by providing longer service and by permitting the ships to operate at designed speeds for longer periods of time. Too, Soviet foundries are learning to cast stainless steel propellers and an incentive is needed so that manufacturing will be undertaken on a broad scale. In fact, it is recommended that a special foundry, equipped with its own Design Bureau, laboratories and personnel, be established to do research in propeller building and build propellers for high speed ships. A further recommendation is a special school to train specialists.

All this is needed in order to revamp the present system, one which involves having to order propellers from plants which do not actually specialize in such work so that the foundries, claiming higher priority work, frequently take two to three years to make delivery. The net result is that the company either ties up a ship for lack of a propeller, or operates it with a faulty one, thereby incurring higher costs.

### SOVIET PORTS

According to one of the Deputy Ministers for the Maritime Fleet, Yu. V. Savinov, the sea coast of the Soviet Union is over 40,000 kilometers long, and is washed by the waters of 12 seas and 3 oceans. Using 1940 as a base, Minister Savinov claims that the cargo turnover for the Soviet merchant marine is, at present five times as great and that cargo carried from the Soviet Union to foreign ports in this same time period is up 25 times. This has, obviously, come about as a result of the build up of the Soviet merchant marine, which is, today, some four times as large as it was when the Communists took over and is composed of a great many new and modern ships.

But progress is not without its problems and a spate of problems were dealt with at a December meeting of the Ministry, evidently important enough to have drawn First Deputy Chairman of the Council of Ministers of the USSR, A. N. Kosyigin, as a speaker. This conference reviewed questions dealing with measures for the improvement of maritime transportation, improvement in the operational aspects of such transportation, lengthening the winter season in the sea ports of the USSR, increasing the use of these ports and a more even distribution of the load placed on them, increasing the facilities for handling both ships and passengers in these ports.

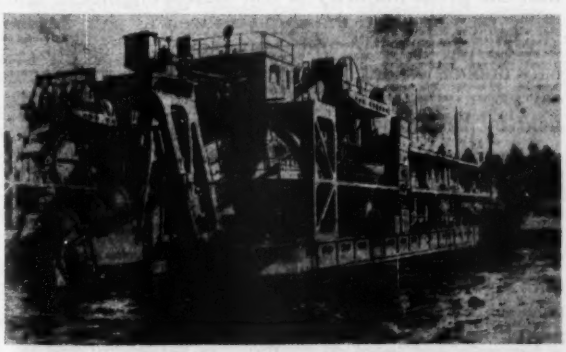
Part of the concern stems from the fact that the Soviet merchant marine, in the first eight months of 1960 had, in Soviet ports alone, piled up a figure of 10,700 ship-days of demurrage, a figure which was up 2.3 per cent over the same period of 1959. Loss of operational time in the Northern Steamship Company was 26.9 per cent higher over this same period; 26.4 per cent was the figure for the Murmansk Steamship Company; while that for the Baltic Steamship Company was a startling 92.7 per cent. The average turnaround time for seagoing dry-cargo ships engaged in the coastal trade was 9.35 days, and 56.6 per cent of this time was standing time in the ports.

While newer ships enabled the operators to cut passage times, the work standards, or norms, in the ports have failed to keep pace with the more economical ships. In fact, the unit time of 3.307 ship days for handling ships is 73 per cent higher than that logged in the same period last year. The standards, as now set, make it impossible to speed up turn around time in the ports. Compounding the problem is the fact that ports under the jurisdiction of organizations other than the merchant marine set

their own norms. Thus, a planned two-day stay turned to an eight-day one in a port under the jurisdiction of the Kamchatka Fish Combine. These losses of operational time come about as a result of disorganization in the work on the docks, arbitrary changes in traffic schedules, inoperative equipment, lack of manpower or lack of fuel, or both, waiting for tugs, waiting for cargo, etc. In September, for example, the Black Sea Steamship Company, largest of all the operators, chalked up over 1,400,000 ton-days of demurrage.

And over and above the causes for demurrage mentioned is that connected with silting and water depths. Silting of approach channels is one of the more serious problems in the way of increasing cargo turnaround, and ship turnaround as well, in certain of the ports. Silting is a particular characteristic of the Baltic Sea coast and, in such ports as Ventspils, Liyepaya and Klaypeda, the annual cost of clearing these channels runs to tens of millions of rubles. In an effort to cope with the problem Soviet planners have built dredgers and have placed orders abroad for additional ships of this type. Among the Soviet yards building dredgers is the "Leninskaya Kuznitsa" Shipyard, which also sends its products to the Soviet rivers. One such is the multi-bucket dredger *Kamskiy-29* (see cut). Other dredgers, including suction types, come from Czechoslovakia and are taken down river through East Germany, Poland and then into the Baltic to Leningrad, or other ports. East Germany is a supplier of diesel-electric dredgers, a series which began with *Neva-1* and is now up to number 4. Where insufficient water is the problem, or where no facilities are available, as is the case in the Far East, barges and landing-craft types are used. A more recent innovation is the reported use of an MI-4 helicopter as a sort of flying crane, used to lift cargo directly from the ship to the land area involved.

Efforts are now afoot to determine the reasons for the silting along the Baltic coast. These efforts involve scientists from the Scientific-Research Station of the Leningrad Higher Maritime Engineering School *imeni* S. O. Makarov and from the Leningrad Maritime Scientific-Research Planning organization, who have begun to make actual observations of the silting of the channels leading to the Baltic ports. In the next two or three years a survey ship, *Yug,* will be used to make oceanographic observations in the Baltic. The ship will be refitted and will have the wheel house rebuilt to accommodate a "Donets" radar, a PEL-1 fathometer and radio equipment, a hydrographic laboratory will be installed and an automatic hydrographic-meteorological station will be equipped. Electromagnetic measuring devices will be used to measure current and radar beacons will also be used to assist in these measurements. One area has already been explored, that in the area of Ventspils. Here currents have been determined for various winds and types of bottoms and this information will be used to arrive at preliminary conclusions as to the causes of the silting up of Ventspils approach channel.



**Multi-bucket dredger *Kamskiy-29*, a product of the "Leninskaya Kuznitsa" Shipyard, assigned to the Kama River.**

Not all approaches are from seaward, however, nor are all the causes of silting directed coastward from the sea. Three survey ships, *Akademik Kurnakov, K. Deryugin,* and *Ladoga,* for example, recently returned to Leningrad from Lake Ladoga where personnel of the Laboratory for Lake Study of the Academy of Sciences of the USSR had been working for a year, taking temperature readings, studying the various natural effects and the availability of food for fish life. Far to the south, in the Volga-Don basin, the survey ship *Akademik Dubinin,* which is assigned to the Novocherkasak Scientific-Research Hydro-Chemical Institute of the Academy of Sciences of the USSR, wound up its eighth year of operations. Last year this small, motor-sailing schooner made two 45-day trips on the Tsimlyanskiy, Stalingrad and Kuybyishev reservoirs, then spent some weeks doing research work in the Sea of Azov.

All this work is part of a plan calling for basic, technical reconstruction of all Soviet seaports at a cost said to be in excess of that spent in the past 12 or 13 years combined. Dredging work alone involves making the ports deep enough to accommodate ships drawing up to 37 feet, no small task. To do this, according to Soviet estimates, will involve the removal of an amount of silt equal to half again as much silt as has been removed in the past eight years. Dredgers, already mentioned, were ordered to carry out this work.

Other work calls for the elimination of certain bottlenecks caused by lack of covered storage space, as well as inadequate open storage space, particularly in those ports engaged in handling general cargo for export. Other ports are inadequately serviced with rail spurs and many do not have all-weather surfaced roads between storage areas and the docks so that, in bad weather, the tractors used to move cargo are slowed down considerably or, in many instances, cannot operate at all.

If, in addition to those problems already mentioned, further problems arise in connection with an expanding merchant marine and an expanding foreign trade, the solution cannot but involve expenditures to expand the ports, including such service facilities as electric power cables, water lines, fuel supplies and steam. In fact, in most ports bunkering facilities, or the lack of such facilities, are a continuing source of trouble.

Finally, once any plans are approved there remains the problem of making the changes and alterations so as not to interfere with, or interrupt, day-to-day operations of the particular port. Herein lies yet another problem. The actual construction work, in many instances, is under the jurisdiction of the Ministry for Transportation Construction, or a similar organization, to which the Ministry for the Maritime Fleet merely transfers its funds to pay for the work, and hopes for the best. Delays in construction work have been known in Odessa, Yalta and other ports. Reassignment of funds to other work is noted in the construction of a mole in Novorossiysk, where work did not get started on time because the funds assigned had gone to other work and equipment needed to do the work on the mole had not been procured.

Obviously, reports on progress can be expected. It will be interesting to see how the problems are solved.

### COMMUNICATIONS

Ships assigned to the Far East Steamship Company are having their radio installations modernized, the old types of installations being replaced by modern sets at a pace which is supposed to see all ships equipped with completely modern installations by the end of 1961. However, according to the Assistant Chief of the Communications Service for the company, A. Shcherbakov, the question of designing an emergency radio installation for life boats, raised some time ago, has never been answered and Soviet industry is not yet producing such an installation.

Yet another requirement is for a radio telephone installation operating in the frequency range of 156-162 megacycles. Thus far the merchant marine has had to use the "Urozhay" set, which, it is said, is of little use for maritime radio communications.

The Administration for Communications and Electrical-Radio Navigation of the Ministry for the Maritime Fleet is urged to press the factories to produce the needed equipments.

Among other types of navigation equipments mentioned is the "ABR" gyro-pilot, an experimental model of which has been tested satisfactorily, not only in the Far East, but in the Black Sea as well. The tests were concluded two years ago, but nothing further appears to have been done to produce the unit for regular use.

### RADAR

Many of the ships assigned to the Volga Tanker Steamship Line have been outfitted with the "Stvor" radar, as well as with "Reka" fathometers. In 1959 ships assigned to this line, which bears primary responsibility for hauling petroleum products on the major rivers in the Soviet Union west of the Urals, used their radars to cover over 9,000-kilometers. However, the "Stvor" has not worked out well in service, and, according to reports, breaks down all too frequently. As of 1 September 1960 almost 30 per cent of all radars installed in Volga Tanker Steamship Line ships were inoperative.

Reported cause—excessive sensitivity to vibration. This defect appears to have been well known, but despite this, installations have been made without the use of shock mounts! Lack of qualified maintenance personnel is a contributing factor where vibration is not a direct cause.

For this latter reason it has been recommended that personnel be trained during the winter season and that the present system, termed "no good" by one Soviet writer, be revised accordingly. It is pointed out that the majority of the navigators have no idea of how the instruments operate and that breakdowns frequently occur because of sheer ignorance of basic operating principles.

Courses are underway in the steamship line this winter in an effort to eliminate part of the cause of the poor performance which has been obtained.

### PERSONNEL

In the light of the foregoing comment concerning personnel, consider that the number of engineers, technicians and the like has, since 1926, increased some 18 times. Water transportation in particular has obtained personnel with engineering and technical training in considerable numbers. There are, today, three times the number of specialists with higher educational training than there were ten years ago. In the past six years over 4,000 graduates of institutions of higher learning have been assigned to the river basins. It was not too long ago that the great majority of the mates, engineers, and other personnel on the ships, as well as ship superintendents, foremen and shop chiefs in the ship repair and other enterprises, were those with practical experience only. Today jobs such as these are held by "highly educated specialists."

Even these specialists were unable to keep Z. A. Shashkov in his post as Minister for the River Fleet. He was summarily fired, without explanation, on 25 October 1960 after a long career, during which he had once headed a combined maritime and river ministry. About the only clue as to the reason for the dismissal of the man who presided at the opening of the Volga-Don Canal is in river fleet statistics which suggest that the Ministry will not meet its assigned goals for 1960.

His replacement is the former chief of the Volga Combined Steamship Line, S. A. Kuchkin, a veteran river man and long time head of the largest of all the river lines in the Soviet Union.

### COSTS

Piston pins for the 3D6 engine, if manufactured by the Barnaul Works of the Altay Council for the National Economy (*Sovnarkhoz*), cost the Soviet buyer 74 rubles. (The prices cited are the old ruble rates, as distinguished from the recent ruble rate change.) If, however, these same piston pins are made by the Derdyansk Works of the Ministry for the Maritime Fleet, the cost per item is 340 rubles. A piston for a DR 30/50 diesel engine, made by the Baku Ship Repair Yard *imeni* Parizhskoy Kommunyi, costs 1400 rubles, but if the same piston is made by the "Russkiy Dizel" Works of the Leningrad *Sovnarkhoz* the cost is only 736 rubles. Piston rings for the I-27 SP engine, if manufactured by the Melitopol Works of the Zaporozhye *Sovnarkhoz,* are three times less expensive than those made by the Vyiborg Ship Repair Yard. According to incomplete data, spare parts for foreign diesels, as well as for Soviet diesels which are no longer in production, are manufactured by over 80 enterprises, 33 plants make pistons, 30 make cylinder liners, 25 manufacture cylinder heads, 20 make bushings, etc. In addition to differences in costs, many of the enterprises which manufacture spare parts do so at a quality level which does not satisfy the consumer.

It is claimed that only specialized production will result in satisfying the needs for sufficient quantities of high-grade, cheap parts and units for diesel engines. The problem has been taken up by the All-Union Planning-Technological Institute. This organization has proposed grouping the plants into three area groups: southern maritime, northern maritime, and Volga; the groupings based on territorial conditions, variety of engine types and sizes, and engineering possibilities of the plants concerned. It is proposed further that parts for foreign engines, as well as for Soviet engines which are no longer in production, be organized in specialized enterprises, enterprises which should be organized in those basins which need the parts. Diesel building plants, it is recommended, should concern themselves with the manufacture of units and parts for engines in production in Soviet plants at the present time.

Another suggestion, this one by the Ministry for the River Fleet, is that the engine builder of Soviet engines in production deliver the spare parts whereas, for engines imported in series, Skoda and Bakau-Wolf types, parts should be provided by machine building plants which would be provided with the necessary equipment to meet the demand. The Ministry proposes that production of spare parts for non-serial engines and for engines which are no longer in production be undertaken by the enterprises which do the repair work on such engines.

Two proposals have been advanced—and remain proposals. The Institute sent its proposal to one of the divisions of the Gosplan of the USSR two years ago, without result. Writers say a speedy solution to this problem of specialized production of spare parts for marine diesel engines is required.

### CASPIAN SEA

The present 7-year plan contains a provision that, by 1965 there will be in operation between Baku and Krasnovodsk five ferries, the first of which is now under construction. It will be recalled that each ferry is designed to carry a train made up of 30 4-axle cars, as well as 300 passengers. The crossing is scheduled for twelve hours and the first such crossing is scheduled for 1961, sometime.

One of the bottlenecks, perhaps two, is the construction of the ferry slip at each of the port terminals. This work involves the clearing out of almost a million cubic meters of earth and the pouring of over 40,000 cubic meters of concrete. In addition the shoreline has to be strengthened with 25,000 tons of rock and several thousand tons of reinforced concrete pilings have to be driven. Late in the year 1960 complaints began to be heard to the effect that little work was being done. In the first nine months of 1960, for example, of a planning total of 4 million rubles work, but 28,000 rubles had been done, this in Krasnovodsk. Less had been done in Baku. It appears too that the plan had been cut in half in July and the funds thus released were used up in dredging operations. A cement plant and a quarry which were to be opened in Krasnovodsk had not been and a floating crane in Baku was inoperative because some of its parts had not been sent along.

Meantime, new ships have been arriving and, at the end of the summer of 1960 there were eight new cotton-timber carriers of the *Inzhener Belov*-class in operation. However, despite the economy of operation of these ships, they have lain idle for as long as ten days at a stretch for lack of cargo. The ports, particularly Baku and Astrakhan are said to be unprepared to handle large cargo ships. Baku has a small cargo pier which must handle all incoming and outgoing cargo. Stored on the pier are "mountains of grain and salt," along with timber and steel. A timber dock was started in 1957 and the first section of it was finally completed in 1960. Two more berths at the dock are to be completed only after the construction people finish the ferry slip mentioned above and workers become available.

Astrakhan seems to be faring badly in handling timber, the port taking an average of two days to load from 3,000 to 3,500 tons of timber. A floating crane with a long boom reach and a capacity of from 10 to 15 tons would help and, in fact, three

such cranes could do the same job in less than a day.

Sulphates, an important cargo on the Caspian, move from Bakdash to Makhachkala, as well as to Astrakhan in the summer time. Shipments are increasing steadily, but ships encounter great difficulties in carrying this cargo. The one dock in Bekdash is falling into decay and a ship cannot load more than 700 to 800 tons of sulphates in a day. A new dock is being completed, but since it has no cranes available, will be virtually useless. The Turkmen *Sovnarkhoz* has ordered 10-ton automobile cranes but the three on order had not, at year's end, been delivered.

It is expected that 13 cotton-timber carriers will be in use by the summer of 1961, but full utilization, based on available reports, is doubtful unless drastic changes occur.

Changes have occurred on the Caspian in the use of the shallow-draft tankers of the *Oleg Koshevoy*-class, to the extent that a tanker named *Agamali Oklyi*, built in the Soviet Union in 1931 (6280 GRT, 85000 DW), has been transferred to the Black Sea. She made her last run from Baku to Astrakhan early in November and, depending on the weather conditions, was held there until next spring, or may have started via the Volga-Don Canal for her new destination in the Black Sea.

## Vibration Forces in Screwshafts

Much attention has been paid in recent years to the effect of the number of blades on the propeller on the thrust and torque variations and the virtues of the five-bladed propeller have been put forward strongly by many workers. Much has been said about the use of five blades instead of four to avoid trouble with axial shaft vibrations. It is a sound generalisation to say that large thrust and torque variations are encountered with a four-bladed propeller and that these variations are relatively small with five blades. Moreover, with five blades it is frequently easier to avoid the coincidence of exciting frequency and natural resonance which has produced so many cases of axial vibration trouble in recent years. Relatively little attention has been given to the bending moments produced in screwshafts by propellers having different numbers of blades and recent work by Dr. J. D. van Manen and Mr. R. Wereldsma is, therefore, of particular interest. During some model research work which they have carried out under the auspices of the Netherlands Research Centre T.N.O., they have demonstrated the large bending moment variations which exist when using propellers with an odd number of blades. This points clearly to a disadvantage in the use of five-bladed propellers, especially when the problems of the transverse vibration of line shafting are beginning to be more fully realised. So far as is known, there has been no research on the full scale to obtain guidance on this matter, but a shipboard investigation might provide the answers to some of the screw-shaft problems now being encountered.

—SHIPBUILDING AND SHIPPING RECORD
September 15, 1960

"THE IRON AGE"

# *ARE HYDROGEN IONS THE CULPRITS THAT CAUSE METAL CORROSION?*

**ACKNOWLEDGMENT**

*The staff of "The Iron Age" prepared this article for the August 4, 1960 issue of that publication, from which it is reprinted.*

EVERYONE IS familiar with rust. It affects industry in many ways. In the United States alone, the corrosion of iron is estimated to waste about $6-7 billion per year.

Car owners, for example, spend more than $75,000,000 every year for the replacement of auto mufflers. Yet the basic cause of iron corrosion has—until now—been a scientific mystery.

But the riddle is being solved. Based on work performed at the Westinghouse Research Laboratories, Westinghouse Electric Corp., Pittsburgh, a new explanation for the rusting of iron is advanced.

### PIN THE BLAME

The true culprits appear to be hydrogen ions. Known as protons, these ions form one of the primary building blocks of matter.

Water vapor originates the hydrogen ions. Then, the tiny ions penetrate the iron and enlarge the sites where oxygen normally combines with the metal. This spreads the reaction throughout the surface of the iron, causing it to rust destructively.

Until now, a standard explanation for iron corrosion centered on an electrochemical reaction. Tiny local areas on the metal's surface are assumed to act as cathodes and anodes under an invisible liquid film of water. It is believed that they generate minute electrical currents that corrode the iron.

But in pure single-phase metals these tiny local areas can not be found. Part of the problem is that the reactions are considered too complex.

### BASIC ACTION

Westinghouse's new theory suggests that something more basic takes place in the iron, even though an electrochemical reaction may also be present.

In a series of experiments, iron has reacted at 450°C with dry oxygen, water vapor, and mixtures of oxygen and water vapor. These experiments eliminated the conditions needed for electrochemical reactions.

Pure iron wires about as thick as a fine sewing thread were reacted with oxygen and water vapor at 835°F. Idealized conditions were closely controlled. Results of the minute-scale corrosion have been studied under an electron microscope. Objects are magnified up to 300,000 times.

The scientists report that with dry oxygen, iron forms a protective oxide coating. From this coating billions of tiny round oxide whiskers grow. Some of these whiskers are less than one-millionth of an inch in diameter and 30-millionths of an inch high.

**Oxide whiskers form when iron is reacted with dry oxygen. Electron-diffraction analyses show these whiskers to be pure $Fe_2O_3$. Each whisker grows from a specific site on the metal's surface.**

**When iron reacts with a 10 per cent water vapor plus a 90 per cent argon mixture, many thin-pointed, blade-shaped platelets form. Surface density of these platelets is on the order of $10^8/cm^2$.**

### LIKE A GARDEN

Each whisker grows from a single, specific growth site on the wire's surface. Growth resembles individual seeds as they sprout from the ground into separate plant stems.

Next, the wires were reacted under identical conditions—except that water vapor was substituted for the dry oxygen atmosphere.

Moisture, from the water vapor, produces a startling change in the oxide surface. From the growth sites erupt thin, pointed, blade-shaped platelets of iron oxide. These platelets spread across the metal's surface.

Shaped somewhat like blades of grass, they are about one-millionth of an inch thick, 30-millionths of an inch wide and 300-millionths of an inch high.

### DENSE GROWTH

As they grow in size, they spread more than 50 times in area over the sites observed for dry oxygen alone. The spread continues until a density of nearly one billion per square inch of surface area is reached.

The amount of iron rust the platelets represent is 250 times that which forms when the water vapor —and the hydrogen ions it releases—is absent from the reaction.

The illustrations that appear in this article show four transmission-electron micrographs of the crystal habits of localized corrosion products. All specimens were reacted at 450°C for 48 hours.

Consider the first figure. It shows oxide whiskers that form when iron is reacted with dry oxygen. The dry oxygen has a dew point of −78.5°C. Electron-diffraction analyses show the whiskers to be $Fe_2O_3$.

These iron-oxide whiskers are formed in addition to the normal oxide film. The diameter of the nucleation sites on the metal remains constant. Area of these sites appears to be independent of time or the extent of oxidation.

### WATER TO SPREAD

The second figure shows the crystal habits formed when iron reacts with a 10 per cent water vapor plus a 90 per cent argon mixture. Many thin-pointed, blade-shaped platelets form. Electron-diffraction analyses reveal that these platelets are also $Fe_2O_3$. Their surface density is about $10^8/cm^2$.

Note the shape of these oxide platelets. The shape suggests that the site for reaction enlarges as the reaction proceeds. But in the iron-oxide reaction the area of the site remains constant.

Uniform thickness of these platelets reveals that the width of the nucleating area remains constant. One explanation for the water vapor's effect is that hydrogen atoms or ions from the water vapor act to enlarge the area for reaction.

The last two figures show the crystal habits of the corrosion product when iron is reacted with mixtures of oxygen and water vapor corresponding to mole ratios of $O_2/H_2O$ at 30/1 and 9/1.

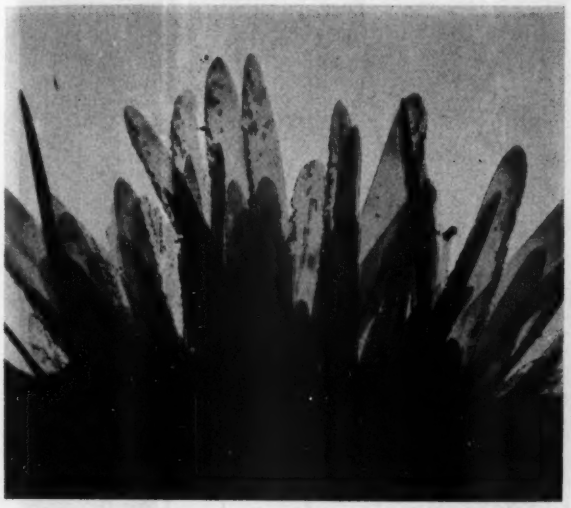
### PREVENT GROWTH

Oxidation platelets are the predominant crystal habit for both environments. To prevent the growth of oxide platelets the $O_2/H_2O$ ratio must be increased to a high value.

At 450°C the influence of water vapor on the localized corrosion process is much greater than its influence on the corrosion of iron at room temperature.

Experiments show that less than one part of water vapor in 200 parts of the dry oxygen atmosphere will cause the blade-shaped crystals to form. At room temperature this corresponds to a relative humidity of about 3 per cent.

Consider in detail the localized growths observed after reacting iron in oxygen and in water vapor



**Oxidation platelets are the predominant crystal habit that results from adding 10 per cent water vapor and 90 per cent dry oxygen.**

**At a mole ratio of $O_2/H_2O$ at 30/1, the oxidation platelets are still present. To prevent their growth, more dry oxygen must be added. The higher the $O_2/H_2O$ ratio, the lower the growth pattern.**

plus argon atmospheres. Assuming the same surface density for the whiskers and platelets, the electron micrographs suggest that the reaction sites in the metal—for the water reaction—are 50 times the area of those observed for the dry oxygen reaction.

The total amount of oxide in the platelets is about 250 times the amount of oxide in the oxide whiskers.

### HYDROGEN IONS

"We conclude that the hydrogen ions in the water vapor enlarge the areas of chemical reaction between the oxygen and the iron and bring about the metal's greatly increased corrosion," reports Dr. E. A. Gulbransen, Westinghouse researcher.

"At the lower temperatures at which iron usually rusts, this basic reaction is masked," says Dr. Gulbransen. "Complex corrosion products are formed and are not stable," he adds, "thus the corroding metal is often removed from the reaction site."

Westinghouse's experiments give a closer insight to the fundamental process involved in iron corrosion. They also help to explain its mechanism.

Once such basic understanding is established, better corrosion control will result. Already two control measures which must be considered in addition to any electrochemical effects that are involved in iron rusting have been pinpointed.

### RESIST RUST

Hydrogen must be prevented from entering the metal. And the growth of the localized reaction sites must be inhibited. Addition of suitable alloying elements to the iron precludes the latter problem.

Rust has been the subject of much speculation and many scientific observations for hundreds of years. For example we have long been intrigued by the iron "Pillar of Delhi" in India. This pillar stands in a dry climate. It has resisted extensive corrosion for more than 1600 years.

Westinghouse's researchers may help us to approach a true understanding of the pillar's remarkable corrosion resistance. Some day this knowledge may prove useful in artificially duplicating the iron pillar's behavior among structures which aren't so fortunately placed throughout the world. This may lead the way to almost uncountable savings in corrosion resistance.

After 70 years as the international standard, the platinum-iridium meter bar at Pais has been supplanted. By action of the 11th General Conference on Weights and Measures, the official meter is now 1,650,763.73 wavelengths of the orange-red line of krypton 86.

—From RESEARCH/DEVELOPMENT
December 1960

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# UP
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75th ANNIVERSARY
ALWAYS GOOD SHIPS

REAR ADMIRAL ALEX M. CHARLTON, U.S. NAVY (RET)

# *SAINT LAWRENCE SEAWAY (OLD STYLE)*

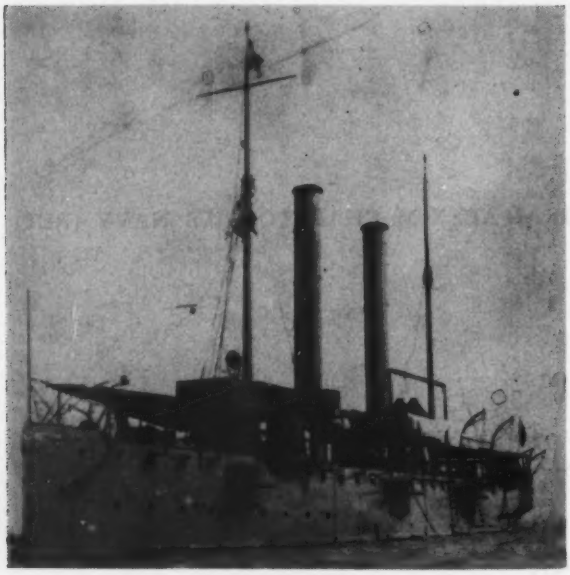
**THE AUTHOR**

***retired from active duty on 1 October 1946 and since that time has lived in Damariscotta Mills, Maine. Prior to his retirement, he had a wide range of duty assignments, including the tour as Engineer Officer of the USS NASHVILLE from 1911 to 1913. Upon completion of this tour, he did post-graduate work in engineering at Annapolis and Columbia University. He served on both the USS TEXAS and the USS TENNESSEE. In 1919 he was selected for engineering duty only. In 1926 while stationed at the Bureau of Engineering he served as Secretary-Treasurer of the American Society of Naval Engineers. He served as Engineer Officer on several missions before made Inspector of Naval Material at Schenectady, New York in 1933. From this post he was made Planning Officer at the Navy Yard in Cavite, P.I. and then Fleet Engineer of the Asiatic Fleet. In 1937 he served for three years as Production Officer at the Navy Yard in Norfolk, Virginia after which he was transferred to Bremerton, Washington as Industrial Manager of the Navy Yard there. From Bremerton he was transferred to Chicago as Inspector of Naval Material where he stayed until 1944 when he was sent to Washington to the Army and Navy Munitions Board and Office of Procurement and Material. It was from this office that he retired from active service. He joined the American Society of Naval Engineers in June 1912 and is still an active member.***

[EDITOR'S NOTE. *The cruise of a major Navy Task Force in 1959 into the Great Lakes through the recently opened St. Lawrence Seaway reminded Rear Admiral Charlton of a voyage from Chicago to Boston through the old Seaway in 1911.*]

IT WAS 99° under the mildewed quarterdeck awnings of USS *Nashville* that Fourth of July in 1911. It was much hotter than that below where we of the 'black gang' were toiling over the ship's engineering plant.

*Nashville* had been in the hands of the Illinois Naval Militia for two years for training purposes. She had deteriorated to the point where a survey had indicated that a major overhaul was necessary —an overhaul which could not be accomplished in Chicago. USS *Dubuque* had arrived in Chicago on June 30th as a replacement training ship, and her crew had the job of getting *Nashville* ready for the trip to the Boston Navy Yard. To maintain *Dubuque* in operating condition while working on *Nashville* was tough on the crew, particularly the engineer force.



**USS *Nashville***
**Taken during Spanish-American War**

I had reported on board *Dubuque* on July 1st as Senior (and only) Engineer Officer, with orders to *Nashville* in a similar capacity when she should be commissioned and *Dubuque* turned over to the Naval Militia. I had been on leave from the west coast and was on my way back when a telegram caught me in Omaha ordering me to Chicago. The Engineer Officer who had brought *Dubuque* up to Chicago had been detached because of illness the day she arrived, so I was a 'new broom.'

The Captain of *Dubuque* was Commander Casey Bruce Morgan, U.S. Navy, whom I had never seen before. His reputation was well known, however, even to youngsters like myself. Fifty years ago the Navy List was small enough so that everyone knew something about those senior to him. "Casey" was known as a 'sundowner' with an irascible temper which frequently got out of control. He knew nothing about me except what he had gleaned from the other officers on the ship and from the Navy Register. From me he found out that I was three years out of the Naval Academy, two as a Passed Midshipman and one as an Ensign; that I had served these three years in the Armored Cruiser *Pennsylvania*, cruising some 75000 miles in the Pacific, and that I had had nine months duty in the engineer department of that vessel.

When I reported to Captain Morgan, his attitude indicated that he wasn't particularly enamored with the billet to which he had been assigned. Bringing one gunboat up to Chicago and taking another back to the ocean wasn't his idea of glamorous duty, even if the voyages did involve considerable seamanship. He looked upon the whole situation including me, his new and unknown engineer officer, with a jaundiced eye.

"Get the *Nashville* ready to live on as soon as you can, so that we can move the whole crew over there. It's a big waste of manpower to have to keep the *Dubuque* steaming while we send a working party over there every day." "I suppose," he added grudgingly, "you know what has to be done."

"I don't know yet, Captain, as I haven't been aboard, but if it was decided to replace her there must be plenty to do, although it shouldn't be too difficult to do it."

"Well, I hope you know enough to do what is necessary."

He didn't seem very hopeful and his attitude irked me. I didn't realize then how a commander feels about an ensign twenty years his junior.

"Captain," I said, rather brashly no doubt, "the Bureau of Navigation sent me here because they thought I was competent to do the job. I'll do the best I can; if it isn't good enough you'll have to get someone else."

It was then that I had my introduction to the low boiling point I was to witness many times in succeeding months. Out of a purple face, a blazing eye was fixed upon me, and I began to regret having put my cards on the table. Before the gasket blew, however, he must have thought it over for all he said was "I hope your best *is* good enough, Charlton; get on with it."

So that was why we were working on the Fourth of July.

The day after I reported to *Dubuque* was a Sunday, so that I had the opportunity to look over the Engineer Division at quarters that morning. I was delighted to see how many old-timers there were—the three Chief Petty Officers, most of the rated men and many of the non-rated men had more than one enlistment behind them—some of them two or three, from the 'hash marks' they wore. It augured well for getting *Nashville* into shape and for her subsequent service. I was to be very glad of the practical experience these men displayed, for in spite of my brave words to the captain, I was still very much of a novice in the engineering profession.

The complement of officers was the usual one for a gunboat at that time—the captain, messing in his cabin by himself, of course, and the other officers in the wardroom—the executive and navigator, the engineer officer, the three watch and division officers, the paymaster and the doctor. The executive officer was Lieutenant Earle Peck Finney, a large, phlegmatic individual, quite the antithesis of the quick tempered skipper. I knew two of the watch officers and the paymaster as they had been in classes below me at the Academy. All the officers felt the way the captain did about getting away from Chicago and back to the coast as soon as possible.

In 1911, "Public Relations," as known in the Navy today, was non-existent. Very little was given out in releases to the Press which might advertise the Navy and make it more favorably known to civilians. Reporters seeking information were usually given the cold shoulder, being looked upon as intruders. So the arrival of *Dubuque* as a replacement for *Nashville*, and the 'doing over' of the latter before taking her away, received the most casual notice in the press. Chicago as a whole didn't know we were there and couldn't have cared less. Even the naval militia people weren't particularly cordial. To us Chicago seemed almost like a foreign port where one might come unexpectedly upon a shield reading "Consul-General of the United States." Much of this attitude was our own fault, I suppose. The Navy was a 'closed corporation' and we liked it that way. All hands considered that they were on the 'inside,' and that civilian life was the 'outside.' Now of course the Navy is an open book, although we do try to write it ourselves (often without complete success).

*Nashville* was built by the Newport News Shipbuilding and Drydock Company from plans and specifications provided by the Navy Department. The contract for this small vessel of 1375 tons, the first naval ship built by Newport News, was signed in January 1894 and the keel was laid in August of that year. At that time, not even the wildest imagination could have foreseen the long and illustrious line of vessels to be built for the Navy, culminating in the carriers *Forrestal* and *Ranger* and the nuclear carrier to come. *Nashville's* length was not as great as the breadth of the carriers' flight decks.

*Nashville* was a twin screw gunboat—length overall 233 feet 8 inches, beam 38 feet and draft 13 feet. The engines were quadruple expansion, perhaps the only ones of that type built for the Navy. An ingenious arrangement allowed the low pressure crank to be disconnected and steam from the second intermediate cylinder to go to the condenser so that the engine could be run triple expansion. The contract speed was 14 knots with a bonus of $20,000 per knot to the company for any speed in excess of 14 knots. The ship was characterized by her slender and very high stacks (over 80 feet). The forced draft blowers built into the ship had been removed for some reason before I joined her in 1911, so that we were very glad to have the draft produced by such a stack height. All the machinery on the ship was driven by reciprocating engines including the two 80 volt generating units, one 16 K.W. and the other 8 K.W. The electric equipment was very meager being limited to 240 lamps, a searchlight, a signalling apparatus and seven small fans. Although built for Caribbean and other tropical duty, no ventilating fans had been provided for spaces below the main deck, reliance being placed upon natural draft ventilators which had to be trimmed to the wind whenever it shifted. (A far cry from 1960 air conditioning).

The propellers were three-bladed with adjustable pitch so that they were removable. We were to be glad of this fact later, as will be seen. On the ship's trials the engines turned up over 300 rpm and a speed of 16.3 knots was recorded. This 2.3 knots over the contract speed netted the company $46,000 but in spite of that a loss of over $100,000 was incurred in building this ship. The (then) struggling little company took three years to complete the vessel, delivering it in June of 1897. The loss taken, a considerable one for those days may well have been the inspiration for the slogan which appears at the entrance to the Company's offices—"We will build good ships, at a profit if we can, at a loss if we must, but always good ships."

*Nashville* had the distinction of having fired the first shot in the Spanish-American War, when she captured the Spanish ship *Buena Ventura*. Her captain didn't even know there was a war on; After that war was over, *Nashville* was sent to the Philippines for duty during the Insurrection. Later she had duty in European waters, more Caribbean service and in 1909 was loaned to the Illinois Naval Militia.

Getting *Nashville* into the Great Lakes involved a special effort on the part of our State Department. The War of 1812 had engendered great bitterness between the United States and Canada. After the conclusion of the war and the signing of the Treaty of Ghent in December 1814, the necessity for peaceful settlement of any Anglo-American difficulties on the Great Lakes was recognized by both sides. The Rush-Bagot agreement of 1817 provided for practical disarmament on the U.S.-Canadian border. The articles of the treaty stated that neither nation should have more than four warships in the Great Lakes or in the St. Lawrence River—none to exceed 100 tons 'burden.' This agreement was very important as it inaugurated a policy of strict peace between the United States and Canada—a peace which has continued without interruption for more than 140 years. Subsequent to the conclusion of the treaty, interpretation through exchange of diplomatic or other official correspondence has served to relax the original stringent restrictions. The tendency, generally, was to permit the presence of naval ships, otherwise excluded, for training purposes.

In order to assist the Illinois Naval Militia in its training for incorporation into the Navy in time of war, steps were taken to get a ship to them. In 1907 the Navy applied to the State Department to obtain permission "from the British Ambassador or the proper Canadian authorities" for the passage of *Nashville* through Canadian waters. In 1908 the British Ambassador assented to this passage provided that the ship pass unarmed and that her use be confined to training purposes. *Nashville* arrived

in Chicago in 1909, was turned over to the Naval Militia and now in 1911 we were taking her away.

The forlorn look of *Nashville* with rust streaks and peeling paint on the hull, superstructure and spindly cigarette-like stacks was accentuated by the run-down look of everything below decks. I had been given a list by the engineer officer of the militia of repairs considered necessary, but it was evident from a very casual inspection that every piece of equipment had to be examined, tested and, if necessary, repaired before we could be sure that the ship was in operable condition.

As soon as we had a generator running to give us light below, I took the captain on a tour of the engineering spaces. His acidulous remarks greatly enlivened the inspection trip. I thought it a good idea for him to see what we were up against.

As many men as we could spare from *Dubuque* went over to *Nashville* every day, going over the equipment necessary to make the ship habitable. The list was formidable, but each day got us farther along as we checked out the boilers, pumps, condensers, salt and fresh water systems, steam lines, ice machine and distilling plant.

The deck force was just as busy as the engineers, getting the topside cleaned up and the living quarters into a sanitary state, chipping rust, red-leading and painting, holystoning the decks and getting the ship back into Navy style. The galley equipment would be considered inadequate today, but it served to get food for the crew and the officers after it had been overhauled. The winches for handling boats were tuned up and the 30 foot 'steam cutter' and the gasoline motor boat put in running condition. Work on the main engines, the steering engine and the anchor windlass was put aside until we were ready for port operation.

After three gruelling weeks, *Nashville* was considered livable. We moved over from *Dubuque* on July 22d and put *Nashville* in commission. With all hands living aboard work progressed more rapidly, the daily difficulties and breakdowns being corrected as they occurred (and there were plenty of them).

The main engines were thoroughly dismantled and then re-assembled as closely to the original measurements as possible. There was no drydock available so that a complete alignment of the shafts from the stern tubes was not possible. Thorough trials at anchor showed no overheating of bearings, so that underway trials were feasible. The steering engine with its wire controls from the bridge and the anchor windlass were given a good workout before we got underway.

We found out at once that without forced draft blowers we would have difficulty in making enough steam to get anything in the way of speed. The six small Mosher boilers had inadequate combustion spaces, and even with the inordinately tall smoke pipes it was impossible to burn even good grade Pocahontas coal efficiently or in sufficient quantity. Ten knots was about the maximum we could get out of the engines with all boilers lighted and the throttles wide open.

During the underway trials the ship was swung and the magnetic compasses adjusted (the gyro hadn't gotten down to gunboats then). The primitive radio equipment was also put into operating condition. Fire, collision, abandon ship and man overboard drills were held frequently until the crew felt at home in its new environment. After several days of trials we were ready to go.

Provisions were put aboard and the cold storage filled. And as usual in those departed days, we restocked the wine mess. We were fortunate in finding most of the spare parts for the machinery aboard—few of them had been used in the two years the ship had been in Chicago.

On July 30th we got underway for Boston. The gleaming white hull, buff superstructure and smoke pipes and shining decks were a great contrast to the slatternly look a month before.

We staggered along at eight or nine knots most of the time, stopping or slowing down frequently to correct some minor derangement. A voice tube ran from alongside my bunk to the log desk in the engineroom, so that I could hear the various machinery noises without difficulty. Very shortly I became accustomed to the rhythm of the engines even when asleep, so that any pronounced change would bring me up standing. We must have presented an astounding picture to any passing ship, for due to the incomplete combustion of the coal in our boilers, we were like the guide for the Israelites coming out of Egypt.

"by day in a pillar of cloud . . . and by night in a pillar of fire . . ."

The voyage proceeded uneventfully as we went the length of Lake Michigan and turned south into Lake Huron. Just before we arrived at Detroit, however, there was a sudden thump and great vibration in the port engine. The propeller had evidently hit some submerged object and lost or bent a blade. We limped into Detroit on one engine and tied up at the Parke-Davis wharf. Very fortunately our diving equipment was complete and the Chief Gunner's Mate was a master diver. His inspection showed that one blade of the propeller had sheared off a foot from the hub. The blades of the wheel were secured to the hub by studs in slots so that the pitch could be adjusted. By coming up on the nuts, a blade could be removed. We found spare blades in the steering engineroom, and soon had one rigged over the stern. Although the water was filthy dirty, as might be expected off a drug factory, our diver adjusted the pitch of the new blade so nicely that no change was found necessary when we docked in Boston. The job took two days with the skipper fuming constantly at the delay, of course. Going on across Lake Erie, we arrived at

Port Colburne the terminus of the Welland Canal on August 5th.

The history of the Welland Canal goes back nearly three hundred years. Previous to the construction of the first canal, all freight had to be transported overland from Queenstown on the Niagara River to the mouth of Chippewa Creek above Niagara Falls. This portage was considered of such importance that it was controlled by a French military post as early as 1678. It passed into British hands in 1759. In 1764 a capstan incline was built on the east side of the Niagara River to the top of the escarpment, 325 feet high, from which a wagon portage about six miles long was used to carry bateaux and merchandise to the head of the Falls. In 1824, due to the initiative of one William Hamilton Merritt who needed water for his grist and saw mills, the first Welland Canal was started. It was completed in 1833, with 40 wooden locks 110 feet long, 22 feet wide and a depth over the sills of 8 feet. This canal was enlarged between 1841 and 1850. By increasing the lifts, the locks were reduced to 27 in number, and permitted vessels of 140 foot length, 26 foot beam and 9 foot draft to ascend from Montreal to Lake Erie. The construction of the third Welland canal was begun in 1873 and completed to a 14 foot depth in 1887. The 25 locks were built of stone and were 270 feet long (with a usable length of 255 feet), 45 feet wide and had a depth over the sills of 14 feet. This was the canal we used in 1911.

It was quite different from the canal now in use. The length of the canal (26¾ miles and the total drop (327 feet) are the same, but the present canal has but 8 locks. All are considerably over 800 feet long, with a width of 80 feet and a depth over the sills of 30 feet. Lifts average about 45 feet. Of the 8 locks three are twin locks and so permit uninterrupted passage in both directions.

The 1911 canal locks presented the same clearance problems, more or less, for *Nashville* as the newer locks did for *Macon* on her memorable voyage in 1959. It was a tight squeeze for both ships, but *Macon's* problems were undoubtedly more vexatious and dangerous than those of *Nashville*. Published accounts of the difficulties encountered by *Macon* show that they completely overshadowed those of *Nashville* forty-eight years earlier.

We entered the first lock at noon and the activity in the engineroom was in great contrast to the comparative quiet of the voyage down from Chicago. Captain Morgan decided he would handle the ship into each lock under her own power. With the constricted spaces to get into, much maneuvering was necessary and the engineroom bells rang continuously. The captain had forgotten how long it takes to reverse a reciprocating engine after a signal is received. As a consequence, we couldn't get the engines set up for one signal before another one was rung up. Many bells were passed up entirely. He never knew the difference, apparently, for there were no complaints from the bridge. We could hear loud and profane imprecations, however, drifting down the voice tube from the engineroom to the bridge, so things must have been hot up there. (I was told that a frequent gesture of the captain in moments of tension was to pull off his cap and throw it on the deck.)

A canal lock is very similar in appearance to a drydock, but the procedure in using the two is quite different. When the bow of a ship crosses the caisson sill of a drydock the responsibility of her commanding officer ceases. The vessel is warped into the dock under the orders of the docking officer. He must place her with the correct clearance fore and aft and thwartships so that when the dock is pumped dry the ship will settle properly on to the docking blocks. Great care must be exercised, of course, to maintain the vessel's position exactly until she is no longer waterborne.

Going into a canal lock, the commanding officer has the responsibility for getting his ship in (under her own power in the case of *Nashville*), and for preventing undue movement as the water runs out of the lock. When the clearances between the ship's sides and the lock walls are small, as they were in our case, care must be taken to prevent rubbing of the sides. But any precise position of the ship is unnecessary as she is still waterborne when the water level in the lock is down to that of the canal reach ahead.

When the ship was in a lock and secured, the gate astern of us was closed and the water let out rapidly through the gate ahead. One had a claustrophobic feeling as the ship let down into the narrow chasm past the dripping gray stone walls so close aboard. With the lock level down to that of the reach ahead, the gate across our bow was opened and we proceeded to the next lock (speed limited to four knots). Forty-eight hours later when the process had been repeated twenty-five times, it was an old story and the first excitement became dull routine. It was a relief however to get into the quiet waters of Lake Ontario and head for Kingston at the head of the St. Lawrence River.

The 1907 Sailing Directions published by our Hydrographic Office stated "the river from Lake Ontario may be divided into three sections: The upper (or Thousand Island) section, 62 miles from Kingston to Ogdensburg through which there is free navigation; the middle (or International Rapids) section, about 54 miles long, from Ogdensburg to St. Regis, through which navigation is interrupted by rapids and shoals around which canals have been built by the Canadian Government; and the lower section 66 miles in length from St. Regis to Montreal which has been improved by the Canadian Government by building canals around the rapids."

The voyage down the river through the Thousand Islands is still very vivid in my memory. There are

some 1700 islands in this stretch of the river, ranging from those some 50 square miles in area to tiny specks so small that they are uninhabited. At that time of year (early August), the area was swarming with people, and we were accompanied by scores of small craft and greeted from every house as we steamed along. The green of the trees contrasted sharply with the blue of the water sparkling in the sunshine. Looking at the peaceful scene, it seemed like "free navigation," but there were more than 11 pages in the Sailing Directions covering the passage from Kingston to Ogdensburg.

The Sailing Directions also said succinctly "The St. Lawrence River below Ogdensburg should be navigated only by experienced pilots." We took one.

That portion of the river between Ogdensburg and St. Regis is the worst part to overcome. For vessels ascending the river four canals were necessary to get around the rushing flow of water in the rock-strewn rapids. In descending it was easier. Below Ogdensburg we came to Galops canal. Instead of seven miles in this canal to bypass Galops rapids and those at Cardinal and Point Iroquois, we had to use only one mile of this canal to get by Galops rapids, and then came out into the river.

Immediately we found ourselves in rapids too swift for most vessels to surmount going upstream. We careened along at a speed never before or afterwards attained by *Nashville*. Through the rapids of Cardinal and Iroquois and a little later those at Rapide Plat and Farran's Point, we held our breaths as we pitched and yawed down the river. I experienced nothing like it until many years later when I shot the Yangste rapids.

It was more normal to get into the Cornwall canal and start locking down again. In 11 miles the six locks of this canal drop a ship down 48 feet, bypassing the dangerous Long Sault rapids on the way. From the placid water of the canal we could see waves fifteen feet high as the rushing current hit partly submerged rocks in the river alongside.

The recently completed work in this International Rapids section of the river to make it navigable for large ships has made it unrecognizable to an old timer. The old canals, locks and even the rapids are now ninety feet under the surface of the new Lake St. Lawrence formed by the backing up of water some thirty miles behind the huge control and hydroelectric dams at Cornwall and Massena.

We passed through the thirty-three miles of Lake Francis and then negotiated the Soulange canal, dropping 84 feet in four locks to avoid Coteau, Cedar and Cascade rapids; then through Lake St. Louis and into the Lachine canal, dropping 45 feet in five locks to get around the St. Louis rapids.

Montreal was just around the corner, and we were very glad to get there, with nothing between us and Boston but the usual hazards of seagoing. We had been in and out of forty-one locks without misadventure, using the engines for all of them. The ship had dropped down 568 feet between Chicago and Montreal.

After taking on coal at Montreal and stores at Quebec we continued on our way, anticipating a pleasant summer cruise the remainder of the trip.

However, as a postscript to the voyage down the river, there was one more incident to be put into our 'memory books.' We were well out into the Gulf of St. Lawrence when our radio picked up a warning of a bad blow from the south. To play it safe the captain took the ship into St. George's Bay in Nova Scotia where we would be adequately protected. Unfortunately the storm veered around completely and instead of being in a safe harbor we were on a lee shore. To keep from dragging on to the beach, we steamed up to the anchor keeping all strain off the chain. Imagine our astonishment when we hove in the anchor after the blow, and found the supposedly holding fluke of the old-fashioned anchor had broken off close to the shank! We had been steaming for two days up to 60 fathoms of chain.

Boston *was* a haven.

"THE CHARTERED MECHANICAL ENGINEER"

# *ON AUTOMATIC CONTROL*

**ACKNOWLEDGMENT**

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## INTRODUCTION

AUTOMATIC CONTROL is playing an important role in modern technological society. Its importance is increasing at a rapid pace as the complexity and scope of the problems which must be dealt with grow. The world sadly needs leadership of the very highest caliber. To provide this the able human mind must be relieved of all tasks which can be handled in some other fashion. More and more there is movement toward a society where man's efforts are spent in controlling the distribution and utilization of power and relatively little energy is directly supplied by man. If the western world is to maintain a position of influence and to continue its traditional support to individual freedom, talented men must be used to their fullest capacity in situations where judgment, wisdom and creativity are indispensable. Understanding of control phenomena must therefore continue to develop.

In addition, such understanding can yield the basis for the design of some automatic control systems to operate in situations where human control fails; where man's response time is too slow or where fatigue is too great an element or where the environment is destructive to health.

The need has been recognized by a very great increase in research and development during the last two decades, particularly in Great Britain and the United States. There has occurred a spectacular growth of the use of instrumentation and control devices in many industries and in other social situations.

## HISTORY

### *The human body: a model for study*

In the workings of his own body man has had examples of superb control systems which far outrange in sophisticated design anything that he himself has been able to achieve. The temperature of the body is held to within a few tenths of a degree in the presence of large and sudden changes in environmental temperature. The eye rapidly changes its optical characteristics to meet changing object distances. The fingers of a selected few of our contemporaries respond to extremely complicated low-energy signal inputs to produce creative works of outstanding artistry. Norbert Wiener [1] and Arturo Rosenbleuth [1] have used concepts of "feedback" in their research aimed at understanding certain neurological phenomena. By work of this na-

ture it is probable that with the human body as a model our capabilities for the design of complex control systems may be extended.

*The speed governor*

However, the advent of automatic control in any real sense did not occur until James Watt made his great contributions to the development of the steam engine in England in the latter part of the 18th century. The steam engine made power available to do the tasks previously accomplished with human labors as well as to provide power in a form flexible enough to make possible new undertakings. There occurred a great flow of men into jobs largely devoted to controlling the power-driven machines.

The insatiable demand for coal to fuel the steam engine forced the development of the first real automatic controller, the speed governor. The use of the steam-driven pump to remove water from the coal mines of England depended upon a reasonable control of speed in the face of a large fluctuation in load. Manual control proved inadequate, forcing the invention of the fly-ball speed governor by James Watt in the period 1780-90. Numerous improvements and alternate versions of this governor then appeared. All of them raised the ever-present problem of accuracy of control combined with stability of operation. However, almost a century elapsed before Clerk Maxwell [2] applied differential calculus techniques to a simplified model of the combined engine and its speed governor thus establishing a rigorous basis for designing and predicting the behaviour of a simple single-loop feedback control system.

The urgent need for the rapid development of power sources combined with the fact that most of the applications were such as to be controllable by the men who moved in an ever-increasing stream from rural to urban industrial life limited the development of control systems. The speed-control problem remained as the predominant one through the dawn of the 20th century receiving renewed attention with the advent and rapid development of the steam turbine. In 1919 Willibald Trinks published his well-known book, "Governors and the Governing of Prime Movers' [3].

*The position servo-system*

During the 1914-18 war N. Minorsky developed the concept of a system which would automatically maintain a ship on a prescribed course. A signal, the difference between the desired course and the actual course, actuated a mechanism which continuously reset the ship's rudder to sustain the proper course. Some years later a vessel of the U.S. Navy was outfitted with such a system. In 1922 Minorsky [4] published his great paper, "Directional Stability of Automatically Steered Bodies.' The generality of Minorsky's treatment laid the firm foundation for the development of industrial process control more than a decade later. In that paper Minorsky clearly presents the case of the use of integration and differentiation elements in the controller to reduce steady-state errors and to increase the stability of a closed-loop control system.

*Feedback amplifier*

In the 1920's telephone communications began the mushroom growth which has so changed the nature of our lives. The Bell System in the United States began to assemble the group of distinguished researchers whose work has been so significant in many areas. While the technical contribution of this group has been great, perhaps even more important has been the creation by an industrial organization of an environment where scholarly work of a distinguished character could be carried on.

One of the early problems on which this group focused was that of signal amplification to compensate for loss in signal strength with transmitted distance. There resulted techniques for the rigorous analysis and design of the feedback amplifier. Perhaps the best known publication documenting some of this work is 'Regeneration Theory' by H. Nyquist [5] which appeared in 1932. The famous treatment of the stability of feedback control systems which bears his name appears in that paper. While people found almost immediate important applications in their own field in the work on communications it was not until after the outbreak of the 1939-45 war that its general value to control design in general was recognized.

*Process control*

Concurrent with the developments in communication outlined above, the oil and chemical processing industry in Great Britain, in Germany, and the United States developed equipment for the control of temperature, pressure and flow. Most of the devices were developed to operate from a low-pressure air supply. There evolved a line of controllers compact in volume, rugged in service, and with adjustable characteristics to meet the needs of a wide range of controlled system parameters. The mechanical engineer was the prime contributor to this movement which has resulted in the availability of low-cost fuels and chemicals in large quantities. While the mechanical engineer has been criticized for the lack of the use of available mathematical tools, this accomplishment was an outstanding one of great importance. It should also be pointed out that in most of his problems the mechanical engineer dealt with a highly complex non-linear system while his electrical engineering colleague faced relatively simple linear phenomena. Many of the steps forward are recorded in the patent files rather than the technical journals. If one were to pick a

single contribution as being among the more significant ones it would be the Callendar, Hartree and Porter paper, 'Time-lag in a Control System' [6].

*Military applications*

By the outbreak of the 1939-45 war the speed of aircraft had reached a point where previous anti-aircraft armament proved sadly inadequate. A great effort was massed in Great Britain and the United States to develop adequate detection and tracking means, suitable computers, and a gun drive which would operate directly upon receipt of the computer output. Electro-hydraulic servo-drives were developed with characteristics far exceeding those of any servos previously built. At the same time mathematical techniques previously developed to solve other problems were brought to bear on the design of feedback control systems. New analytical approaches to the optimization of such systems evolved. Of equal significance was the training of a large number of men competent to do outstanding work in automatic control. When the war ended they flowed into diverse industries and into key teaching posts, enthusiastically dedicated to the belief that the salvation of the world lay on their shoulders. While much work remains before that salvation is complete, the contributions of these men have been great.

The chilly blasts of new world tensions drove many of them back to military problems, to research leading to missile system development; to national and intercontinental defense systems; to satellite programs.

The problems of guidance and control loom large in each of these areas and the scale of the effort is such as to lead us to expect substantial additions to our basic understanding of automatic control phenomena.

*Economic systems*

It is clear that the principles and methods of dealing with the dynamics of feedback control systems have a generality and power to cope with problems arising in quite different kinds of systems from those already referred to. The existence of economic cycles of boom and depression is typical of a certain class of such problems. The indications are that if a model can be devised which adequately pictures an economic society, prediction will be possible of what will happen in response to changes in the economic forces which are of prime importance. The body of feedback control theory plays a major role in this procedure. Keynes [7] has suggested a simple model. Arnold Tustin [8] has discussed the application of closed-loop dynamics to a modification of the model in a book published in 1954.

*Business operations*

The optimization of rate of production and size of inventory to meet fluctuations in sales has long been an important and difficult problem. Again, it appears possible to develop an adequate mathematical model which expresses the actual behaviour with sufficient accuracy to have meaning. Feedback control techniques then can prove powerful in determining schedules of production and sizes of inventory to meet changing sales to yield maximum profit consistent with certain capital restrictions. J. W. Forrester [9] has discussed such an application.

*Processing of metals*

As early as 1818 Thomas Blanchard invented the 'copying lathe.' The first application was the turning of gunstocks. A master shape was used to position the cutting tool thus reproducing the shape of the master on many pieces. More than a century later in 1921 John Shaw invented the Keller duplicating milling machine. Again a master shape is used to store the cutting information. However, a low-force level tracer moving on the master form transforms the dimensional information into an electric signal which controls a high-force output actuator driving the cutting tool. Because of the low tracer forces, inexpensive easily fabricated master forms can be used. During the last decade the development of automatic machine tools operating on digital information contained on cards or tape has received much attention.

The Bendix Aviation Corporation has a series of lathes in operation for the automatic machining of three dimensional cams to be used in aircraft engine governors. Changes in cam design which previously required slow and expensive alterations in the master forms can be made using the digital input system with great savings in time and cost.

The digitally controlled milling machine recently developed at the Massachusetts Institute of Technology is a more sophisticated example in which digital information controls the positioning in space of the table of a large milling machine. Originally designed to machine airplane wings from aluminum forgings it obviously has myriad applications.

The above brief history is far from being all-inclusive. Nevertheless, certain facts shine through. Early developments in automatic control date back to the beginning of the Industrial Revolution in Britain. The explosive growth of steam prime-movers and the machines they powered in the 19th century was not matched by a similar strong growth in understanding of the control problem. Beginning during the 1914-18 war and continuing with tremendously increased effort from the outbreak of the 1939-45 war the research and development of automatic control systems has made spectacular progress. Originally, largely regarded as a mechanical engineering problem in the ancient and honorable traditional sense, control engineering is now the concern of scientists and engineers from many

fields of endeavor. It is an interdisciplinary activity and if the mechanical engineer is to continue to be a major partner in this activity he must be able to roam across the fences which have existed in the pastureland of engineering.

## BASIC CONTROL CONCEPTS

### *Definitions*

Control technology is always concerned with design, construction, and operation of relatively large and complex systems subjected to changing loads and/or requirements. Thus, the unifying central theme is dynamics regardless of the nature of the elements constituting the system. Figure 1 is a block diagram of a simple control system. The 'plant' or 'controlled system' is the productive element. In general it has one or more outputs $C$ which are the *raison d'etre* of the system. The output may be a product, a temperature, a pressure, a flow, a position, a velocity, etc. The behavior of an output as a function of time is the direct result of changes in the values of the inputs $M$ and the characteristics of the system. The plant is shown in more general form in Figure 2. With a linear system the outputs are related to the inputs as indicated by equations.

$$C_1=h_{11}M_1+h_{12}M_2+ \ldots h_{1n}M_n$$
$$C_2=h_{21}M_1+h_{22}M_2+ \ldots h_{2n}M_n \quad \ldots\ldots\ldots (1.1)$$

where $h_{11}$ and $h_{12}$, etc., are functions of time involving the physical properties of the plant. For the system shown in Figure 1,

$$C=h_{11}M_1+h_{12}M_2 \quad \ldots\ldots\ldots\ldots (1.2)$$

The $h$ functions can be and often are cumbersome and the assumption of linearity is, of course, limiting.

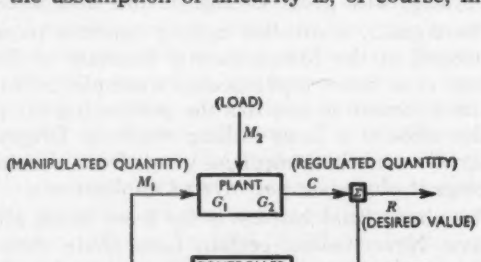


**Figure 1. Simple model of a feedback control system.**

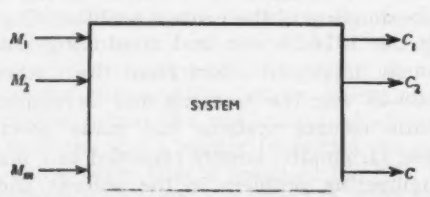


**Figure 2. Block diagram of a plant or system. Three values of gain are shown.**

### *Measuring means*

To control an output of the plant its value at any instant must be known with an accuracy consistent with the desired result. The measuring instrument must therefore have a speed of response which is fast relative to the speed of the plant. It must not load and thus alter the behavior of the plant. To meet such conditions the instrument must operate at a low energy level relative to that of the plant. The measured value of the output $C$ is compared to the $R$, the desired value of $C$, often referred to as the reference value. The resulting output is given below:

$$E=l_R R-l_C C \quad \ldots\ldots\ldots\ldots\ldots (1.3)$$

where $l_R$ and $l_C$ are functions of time. If the instrument meets the condition set above the simplification shown below is valid.

$$E=R-C \quad \ldots\ldots\ldots\ldots\ldots (1.4)$$

where $E$ is the error in the controlled quantity.

### *Controller or regulator*

The error signal $E$ is the input to the controller or regulator which is designed to produce an output $M_1$ which will reduce the error $E$ to an acceptable value in the quickest time consistent with stable operation. Generally the output $M_1$ must be supplied at a high power level relative to the signal $E$, hence a common characteristic of a controller is power amplification. The behavior of the controller is given by

$$M_1=gE \quad \ldots\ldots\ldots\ldots\ldots (1.5)$$

where $g$ is a function of time and the properties of the controller.

### *Feedback loop*

The three elements are interconnected to form a closed loop by the feeding back of the measured behavior of the output to manipulate an input to the plant. This feedback of what is taking place in order to gain control is fundamental to the control process regardless of the nature of the elements involved. The behavior of the simple control loop of Figure 1 is obtained directly from equations (1.2), (1.4), and (1.5).

$$E=\frac{R-h_{12}M_2}{1+h_{11}g} \quad \ldots\ldots\ldots\ldots\ldots (1.6)$$

Equation (1.6) is the basic relationship upon which all linear control theory is based. Its application to complex systems can be difficult and time-consuming. However, certain observations of importance follow directly from the general equation (1.6).

(1) Changes in the desired value of the controlled quantity $R$ and the load $M_2$ will produce errors.

(2) The transfer characteristics of the combined plant and controller $h_{11}g$ must approach in-

finity sometime after disturbances in $R$ and $M_2$ are applied if the error $E$ is to approach zero.

(3) If the transfer characeristic $h_{11}g$ is equal to $-1$ the error is infinite and the system is unstable.

(4) The properties of the plant and the controller are of equal importance in determining the over-all system performance. Hence, the common practice of selecting a controller after the plant design is fixed is obviously a poor one.

*Criteria of performance of feedback control systems*

It is essential to establish criteria of performance toward which the design of the system is aimed. While such criteria may vary depending upon circumstances, the objectives of control can be stated in the following manner.

(1) The error or deviation should be reduced to acceptable values after the application of disturbances to the system, or more briefly: the steady-state error must not exceed acceptable limits. For example, in the speed-governing problem satisfactory operation in certain applications may require that the steady-state error in speed shall be less than 10 per cent of the rated speed when the load varies from zero to rated load.

(2) The error must reach its steady-state value rapidly.

(3) The system must be stable. It must not oscillate excessively.

It should be observed that while the above objectives are common to all control systems, it is not possible to give specific numbers which will hold for all cases. For example, in the temperature regulation of a home, a steady-state error of $\pm 2°F$ is probably acceptable, a time of 30 minutes in reaching the steady state after a disturbance (sudden drop in outside temperature) would be considered adequate, minor oscillation would not be regarded as disastrous. In comparison, the specifications, for certain controlled-atmosphere chambers limit steady-state errors to an order of $\pm 0.1°F$ with a speed of response of a few seconds and with zero or very small overshoot. Thus system performance is always measured relative to the requirements which the system must meet to fulfill its function.

In many cases steps which are taken to ensure small errors and fast response reduce the stability of operation. The final design is usually a compromise yielding the lowest errors and fastest response consistent with adequate stability. The choice of the actual mathematical expressions used to express the criteria of performance is influenced by the ease of application to actual problems.

*Determination of transfer characteristics*

No sound designs can be carried through without a knowledge of the relationships which exist between changes in the outputs of a system and the changes in the inputs which cause them. Obvious as this statement may appear to be it is still the exception rather than the rule when enough information is made available to undertake a sound optimization of the design of a control system. System transfer characteristics are established by:

(1) Calculations based upon previously determined physical laws.

(2) Measurement of output changes due to input changes.

(3) A combination of (1) and (2).

In any event the information required is that necessary to predict the dynamic response of the system to any disturbance.

When the nature of the system is well enough known a model can be conceived which is less complex than the actual system but which adequately describes the actual system behavior and has the advantages of being expressible in mathematical form (very often linear differential equations). Such information can be inserted into equation (1.6) and solutions obtained by the powerful analytic techniques available.

In many instances the system is not known. Then measurements of output response to input disturbance must be used to determine the mathematical equations of the system. This inverse problem is often difficult to handle and in recent years much effort has gone into the development of adequate methods.

*Nature of system transfer characteristics*

The dynamic behavior of a system is formally described by the differential equations which relate changes in the output to changes in system inputs. Equation (1.7) illustrates the general form.

$$A_n\frac{d_nC_1}{dt^n}+A_{n-1}\frac{d_{n-1}C_1}{dt^{n-1}}+\ \ldots\ A_1\frac{dC_1}{dt}+A_0C_1=$$

$$B_m\frac{d_mM_1}{dt^m}+\ \ldots\ B_0M_1+D_p\frac{d_pM_2}{dt^p}+\ \ldots\ D_0M_2\ . \quad (1.7)$$

Similar equations express the relationship of the other outputs $C_2$, $C_3$ . . . $C_n$ to the inputs $M_1$ and $M_2$. For increased ease of handling these equations are often expressed as Laplace transforms. Thus when $M_2=0$ equation (1.7) becomes:

$$\frac{\overline{C}_1}{\overline{M}_1}=\frac{A_nS^m+A_{n-1}S^{n-1}+\ \ldots\ A_1S+A_0}{B_mS^m+\ \ldots\ B_0} \quad \ldots\ldots\ (1.8)$$

where $\overline{C}_1$ is the Laplace transform of $C_1$; $\overline{M}_1$ is the Laplace transform of $M_1$.

Equation (1.8) is known as the transfer function of the system. Similar transfer functions relate each output to each input of a system.

If in equation (1.6) $M_2$ is set equal to zero then:

$$\frac{\overline{E}}{\overline{R}}=\frac{1}{1+H_{11}G} \quad \ldots\ldots\ (1.9)$$

where $\bar{E}$ is Laplace transform of the error; $\bar{R}$ is Laplace transform of the reference quantity; $H_{11}$ is transfer function of the plant; $G$ is transfer function of the controller.

The task then is to select $G$ and utilize whatever freedom exists in the plant design to choose values of the system properties such that the over-all transfer function $H_{11}G$ is optimum.

*Nature of the controller*

The controller is an element of the over-all system which accepts and operates on the error signal to produce an output which manipulates an input to the plant. The most widely used type is one in which the output of the controller is proportional to the error.

$$M_{11}=K_cE \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.10)$$

where $K_c$ is a constant known as the gain of the controller. In any realizable controller the magnitude of the output will be limited as shown in Figure 3. The gain $K_c$ is usually adjustable within limits. Various values of gain are illustrated in Figure 3. The well-known on-off controller is a version of the infinite-gain controller in which the range of the output is biased to occur entirely in one direction with zero output for one sign of the error.

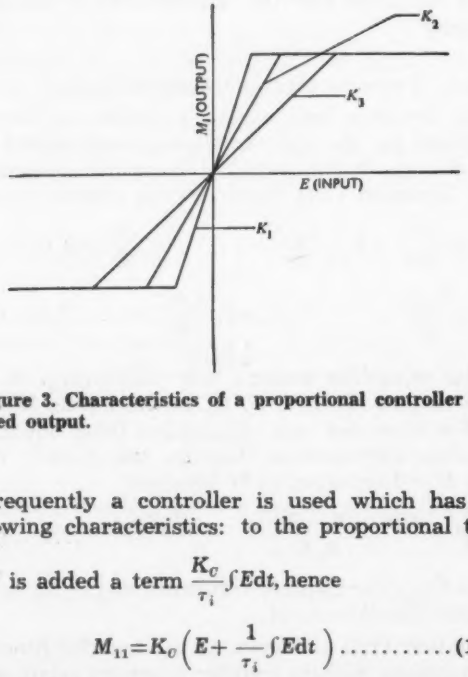


**Figure 3. Characteristics of a proportional controller with limited output.**

Frequently a controller is used which has the following characteristics: to the proportional term $K_cE$ is added a term $\frac{K_c}{\tau_i}\int E\,dt$, hence

$$M_{11}=K_c\left(E+\frac{1}{\tau_i}\int E\,dt\right) \quad \ldots\ldots\ldots\ldots (1.11)$$

A limitation of the proportional controller is its inability to call for a change in its output if the error is zero. If the load on the plant changes, a change in input is required. The proportional controller can provide this only by permitting an error to be established such that $K_cE$ is equal to the required change in input. Thus, the proportional controller must always operate with an error in the presence of any disturbance which requires a change in system input. However, the second term of equation (1.11) can have a value when $E$ is zero. This is shown in Figure 4 for an arbitrary $E$ against time schedule. The proportional-plus-integral-type controller not only provides correction as soon as an error occurs, but it can also maintain a correction in the absence of error.

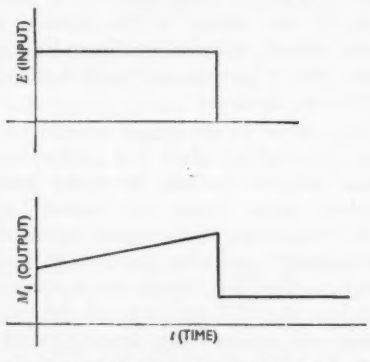


**Figure 4. Output of a proportional-plus-integral controller for an arbitrary error against time input.**

If an element is added to the proportional controller which is a function of the rate of change of error the following controller equation results

$$M_{11}=K_c\left[E+\tau_d\frac{dE}{dt}\right] \quad \ldots\ldots\ldots\ldots\ldots (1.12)$$

In many plants there is a substantial interval between a change in input and the resulting change in output. Thus there is a lag between the time of detection of an error and the time any influence of the proportional controller is felt by the controlled quantity. The addition of a derivative element to the controller makes possible a controller output before an error actually occurs. In a limited sense the error is anticipated and steps are taken to offset it before it actually occurs.

In a single system all three influences are often required. Thus, a three-element controller, proportional plus integral plus derivative, is used. Its behavior is indicated by equation (1.13):

$$M_{11}=K_c\left[E+\frac{1}{\tau_i}\int E\,dt+\tau_d\frac{dE}{dt}\right] \quad \ldots\ldots (1.13)$$

The physical realization of these concepts involves compromises forced by the existence of mass, stiffness, friction, hysteresis, etc., in actual controllers. The so-called compensating circuits perhaps more accurately describe actual performance over a wide range of operations. Nevertheless, the objectives of

design are more clearly illustrated by the above idealized equations.

While the above picture covers directly and indirectly a large number of controllers now in use the future holds promise of significant developments referred to in another section of this paper.

*Measurement and transmission of signals*

The plant and the controller are coupled together by transmission links. One group of such transmission links carries information concerning the values of outputs of the plant, and at many times, the inputs of the plant, to the controller. It is important that such information be accurate and that it be carried with minimum delay and distortion. In many instances it must be transmitted relatively long distances around obstructions. In certain cases even the best available instrumentation supplies signals contaminated with noise to such an extent that the signal must be processed to recover the message before use. The growing knowledge in the area described by 'information theory' has made, and continues to make, important contributions to the handling of feedback control systems.

Data transmission links take various forms: (1) electric; (2) pneumatic or hydraulic; (3) mechanical; (4) human.

Electric transmission is widely used in all kinds of control systems. The great flexibility of wire, its relatively low cost of installation and maintenance, the relative ease of processing electrical messages, and the message speed are important advantages. However, few signals originate in electrical form and in many instances ultimately are not used in such form. Thus convertors or transducers must frequently be used to change a displacement, a velocity, an acceleration, a pressure, a flow rate, and a direction into a voltage or current and to reconvert these electrical signals into some mechanical form for use at the controller.

Pneumatic systems are widely used in industrial applications. In many of them information is transmitted pneumatically, particularly in instances where the length of the data link is relatively short and the time for signal transmission is small compared to the required speed of response of the over-all system. While more difficult to install and less flexible than electrical systems the convertors used at both ends of the transmission line are simple and reliable when used with air-operated control systems.

Where controller and plant are an integral compact unit the transmission by mechanical gears, linkages, etc., can be most effective (for example, an automatic power-steering unit).

In a great many systems the man serves as both a measuring means and information transmission link. In other instances he performs the additional functions of a controller. In certain cases he handles only the data transmission. The driver of an automobile measures his present position, the geometry of the road ahead, the nature of other traffic. He rapidly uses this information to make decisions continuously and to manipulate the steering wheel to carry out such decisions. The measurement and transmission of information occurs at low-power level. The wheel is operated at relatively high-power level.

*Over-all system*

In brief simple terms a limited presentation of the components normally present in a control system has been made. Successful design and operation is vitally dependent upon the thoughtful consideration of the structure of the components. The specification as to what such structures must be is established by system synthesis and analysis aimed at an interrelated design yielding optimum performance of the system considered as a whole. This challenging task is sometimes referred to as systems engineering. Perhaps one of the great contributions of research men in the field of automatic controls has been made because of their insistence that the performance of entire complex systems be analyzed and that the design of each component be based on the criteria thus established.

*Computers*

Concurrent with the growth of knowledge of automatic control there has occurred a remarkable development in computing machinery of both the analogue and digital types. The use of such equipment is indispensable to complex systems' design calculations. In addition, computing elements are being widely used as components of control systems.

## CURRENT RESEARCH

*Self-adaptive control systems*

The performance of any feedback system is determined by the characteristics of all elements of the system. If the characteristics of one or more elements change from design values, the over-all system behavior will generally deviate from the optimum or even from acceptable standards. Thus in a heat-exchanger, corrosion of the tubes can cause major changes in the rate of heat transfer. In a missile-guidance system gain is often a function of target range. In an aircraft engine the characteristics vary widely over the range of speed and load normally encountered. A controller designed for one set of conditions may not be satisfactory for a quite different set of conditions.

One of the most interesting areas of present investigation is that concerned with the design of controllers which will change their characteristics in such a manner as to maintain optimum performance as the conditions of operation of the controlled system change. Such systems are often referred to as self-optimizing or self-adaptive control systems.

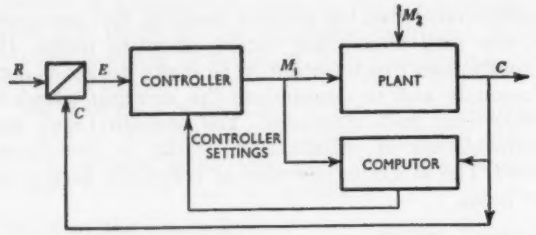


**Figure 5. Simple model of system employing a self-adaptive controller.**

Figure 5 shows a block diagram of a simple feedback control system in which the controller characteristics are being altered as the plant characteristics change. To accomplish this it is essential that at each instant of time the transfer characteristics of the plant be known. With such knowledge the new controller characteristics must be determined. Finally the controller must be altered in accordance with the result.

In certain cases the plant characteristics change relatively gradually over an extended period of time. In other situations the important dynamic relationships of a plant may undergo large changes in a time interval of the same order of magnitude as the required speed of responses of the controlled system, imposing the severest design problems. In either case interesting and challenging questions are raised.

To determine the transfer characteristics of the plant, measurements must be made of the output $C$ and the input $M_1$. Such measurements make available simultaneous records of output and input against time. From these data the dynamic nature of the system may be computed, providing the assumption of linearity is valid. The result may be the step response of the plant, the impulse response of the plant, a model whose characteristics have been varied rapidly until the dynamic relationship between the model input and output is the same as that which exists in the plant, or some other usable relationship or device. Using this information the proper setting of controller parameters must be automatically computed. Finally, the newly computed controller settings must be made.

It is clear that design activity previously engaged in by the engineer is here being assigned to the controlled system as the engineer assumes the more difficult responsibility of designing systems which can reproduce his computational procedures faster and with fewer errors. Out of the work to date the possibility of using interesting and difficult controller characteristics appears strong. Some controllers would be of such nature as to operate with continuous data, others would be particularly designed for use with sampled data.

*Sampled-data control systems*

It is possible to obtain from data collected on a sampling basis rather than a continuous basis complete information, provided the time interval between successive samples is properly selected.

A major research effort is continuing to increase understanding of systems operating in this manner. Computational procedures are well developed. Digital computing equipment is designed to operate on quantized rather than continuous data. The interval between samples makes free time available on certain controller and computational equipment which can be multiplexed with other systems. Hence, by adequate switching arrangements a single controller can be used to control a number of different systems on a time-sharing basis, adjusting its characteristics to each plant as it receives information from that plant.

*Statistical treatment of control systems*

Control systems technology is demanding an increasingly sophisticated treatment of information which passes between and through the subsystems which constitute the elements of the over-all system. Much of the recent work in information theory is based on stochastic operations. Applications of existing methods to control systems subjected to random inputs has figured significantly in recent research work. Few systems are free from some disturbances which are random.

*Non-linear elements*

The purposeful use of non-linear elements to improve the performance of control systems is seriously limited by an inability to deal with non-linearities on a general basis. Both the analogue and digital computers are powerful tools and are playing an important role. They can handle specialized non-linear situations with a certain amount of dispatch. It is true that the describing function technique and the use of velocity-phase diagrams have proved extremely useful in many important situations. Nevertheless, the analysis of non-linear systems remains a vast, largely unknown territory.

Thus, the situation is that, using to full advantage computing machinery, there are few problems regardless of their complexity or non-linear characteristics that cannot be analyzed. If a closed solution in the classical sense is insisted upon there are few systems with non-linear properties that can be handled. There has been, and continues to be, serious work aimed at developing formal methods for handling non-linear systems. Progress has been significant but very limited.

*Nature of commonly occurring non-linearities*

Non-linearities commonly faced fall into two categories: (1) those inherent in the system being

dealt with; (2) those purposely introduced to yield better performance. The first includes backlash, hysteresis, dead space, coulomb friction, saturation, as well as certain basic relationships such as the equation of state for gases, $PV=RT$. In the second category fall the variable-gain controller and the on-off controller. Clearly, in real life more systems are non-linear than linear. Nevertheless, linear theory has been enormously successful in predicting performance and it is with linear theory that much of the successful probing into the frontiers of research of automatic control systems is being done.

### DESIGN

Much of this lecture and indeed much of the literature on control dynamics is devoted to analysis. Analysis is an important tool to the designer. Once a concept is evolved it permits an evaluation of the concept; it provides a means of establishing suitable values of the system parameters; it provides a means of predicting limits of performance; it makes possible a logical determination of specifications of the sub-systems; it can stimulate new concepts. However, design, in the sense used here, is the creation of something which did not previously exist. It is a total job from conception, through detailed delineation, to successful operation. Analysis is an important phase, but only one element of the design process.

Design in its fullest meaning is the top role of the engineer. It is an increasingly more difficult role as the complexity of the systems the engineer must deal with increases. It is true that large and able teams of specialists are brought to bear on many of these problems. Yet such teams do not accomplish the required goals without masterful leadership of individuals, and the strength to make decisions and carry them out using to the very fullest extent all the tools of analysis and all available information of relevance from many diverse fields.

*Stratification of the engineering profession*

The engineering profession has developed into a number of large groups. The members of each group have viewed their area of activity as clearly distinguishable from that of other groups. Engineering schools have also recognized the existence of such boundaries between mechanical engineering, electrical engineering, civil engineering, etc. The profession has conferred the title of engineer upon the man who does routine technical work as well as upon the man of vision whose leadership makes possible great engineering achievements. Hence the engineering profession is stratified with respect to areas of activity and highly diluted in over-all ability for responsible leadership. This is not an effective way to meet the challenge of the future. There must be a breaking down of the traditional barriers between one brand of engineering and another. The picture here presented of the required range of activity of the engineer in dealing with feedback control systems is not an isolated case.

*Certain movements in engineering education in the United States*

The urgent need for engineers who can deal with complex problems involving many disciplines is attracting the attention of some of our leading institutions of higher learning in the United States. Movements to meet this need can be observed more clearly at the graduate level. At both Case Institute of Technology and the Massachusetts Institute of Technology research and design activities in control systems have led to the establishment of interdepartmental laboratories attracting faculty and students from mechanical engineering, electrical engineering, from the management school and from mathematics. Programs of graduate study have been developed which are directed toward developing the breadth of knowledge which this paper indicates is essential to frontier work in control systems design.

At Case, in addition to the Systems Engineering Center, there has been organized at the graduate level an Engineering Design Center, a Center for Urban and Regional Planning, and steps are being taken toward the establishment of a Center for the Study of Matter. All of these groups draw personnel from a number of different departments. All have the common element of being centers for professional investigations and developments of a challenging nature which require knowledge and understanding in more than one of the traditional fields of engineering and science. All operate with advanced graduate students working as junior colleagues of the faculty.

This movement at the graduate level has its counterpart in the undergraduate engineering programs. Traditionally the first year of a four-year program and part of the second year have been essentially the same for all engineering students. The last two years have developed the sharply differing traditional engineering programs. Relatively few students have gone on to graduate work. There is now wide and serious consideration being given to undergraduate engineering programs in which the first three or more years are essentially the same for all engineering students. There is great emphasis on work in the basic sciences, in mathematics, and in the humanities and social studies. An integrated program of study in materials is being developed. Strong efforts are being made to have more of our students regard the undergraduate program as the foundation for advanced graduate work.

At Case such developments are well ahead. However, in addition to great emphasis on the development of analytic skills, there is being developed a

continuous stream of design throughout the entire program. Imaginatively executed and sparked by the presence of outstanding design work on the campus (the Engineering Design Center) this element is the feature which clearly distinguishes the role of the engineer from that of the scientist. In the design of such systems as have been discussed in this lecture the engineer must be able to cope with electrical as well as mechanical phenomena. He must utilize the most powerful tools of computation as they may be required. This is a large order. It requires an extended program of graduate work in association with faculty members who are engaged in actual design work of the very broadest and imaginative nature. It is nourished by recognition on the part of senior leaders of traditional engineering organizations of the tremendously increased scope of their profession. It requires a continuing alertness to the rapidly occurring developments in science and technology and a willingness to move swiftly to make the changes in our educational and professional structure.


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## Hydrofoil Research Contract

Design and construction of a set of super-cavitating hydrofoils for the Maritime Administration will be carried out by Dynamic Developments, Inc., a subsidiary of Grumman Aircraft Engineering Co. Work is to be completed in one year at an estimated cost of about $428,000. An experimental 104-ft. 80-ton aluminum hydrofoil craft is now under construction under a prior contract at Gruman's Bethpage, Long Island plant for delivery Summer 1961. The craft is expected to attain speeds of 60-70 knots using conventional surface-piercing, sub-cavitating hydrofoils. The vessel will carry 75-100 passengers in open seas. The purpose of the new contract is to provide the vessel with a set of fully submerged, super-cavitating hydrofoils, controlled by an electronic autopilot which will attain higher speeds. Above certain speeds the action of water on the oval-shaped sub-cavitating foil creates "cavitation" on the upper surface, impairing the lifting power of the foil, and creating excessive drag. The super-cavitating foil to be developed will use a wedge shape to direct the cavitation to the rear of the foil, where it will not interfere with the foil's lifting power. It is believed such hydrofoils will permit speeds up to 100 knots. The new contract is part of a cooperative hydrofoil research program being carried on by the Maritime Administration in cooperation with the Office of Naval Research and of the Bureau of Ships, Navy Department.

—From MARINE JOURNAL
October 1960

DR. MAX O. KRAMER

# THE DOLPHINS' SECRET

**THE AUTHOR**

*was born in Koeln, Germany, on September 8, 1903.*
*He graduated in Electronics at The University of Munich, Germany in 1926 and received the Doctor of Science Diploma at The University of Aachen, Germany in 1931 while working at the Aerodynamics Institute under Professor Theodore Von Karman.*
*From 1932 to 1943 he was employed by the German Research Institute for Aeronautics (DVL, Berlin, Germany) where he ultimately headed the Aerodynamic Institute and was appointed Senator, or a member of the leading staff.*
*From 1943 to 1945, he headed the Development Station for Guided Missiles at Brackwede, Germany; which developed the remote controlled fighter-born Rocket X-4. From 1947 to 1952, he worked at the Naval Air Development Center, Johnsville, Pa., where he developed an acoustic guidance system for guided missiles.*
*In 1952 he was employed by Coleman Engineering Company, Inc., Los Angeles, California, as Technical Director supervising various research projects. When in 1956, it was decided to concentrate on an invention of his called, "Boundary Layer Stabilization by Distributed Damping," a subsidiary company, Coleman-Kramer, Inc., Los Angeles, was formed for the purpose. Dr. Kramer is Vice President of this company.*

**(The Story of an Invention in the Field of Hydraulics)**

A SCHOOL of dolphins showing off their speed by passing alongside a fast ocean liner in a seemingly effortless glide is a sight to behold. These beautiful air-breathing mammals, six to eight feet long (called porpoise by seamen), seem ready to accept a challenge to a race from anything moving fast on the ocean surface, and the literature fails to report that they ever lost such a race. People who have been aboard Navy speedboats or aircraft carriers will tell you that, even at the top speed of these vessels, the dolphins "still walked away." Some people even claim that during the testing of torpedoes the dolphins nudged these man-made fish off course, as if challenging them to go faster.

Several biologists [1, 2] have, many years ago, stated their opinion that the speed of the dolphin cannot be explained by our current hydraulic knowledge; that somehow the dolphin must have a secret which explains its brilliant performance. Some suspected that the dolphin might establish fully laminar, or turbulence-free, flow at its skin. If this were so it would cut the drag to roughly one-tenth of that encountered by comparable man-made hulls, with their predominantly turbulent surface flow. However, the biologists could not explain how the dolphin might accomplish this change in flow pattern.

The problem of establishing laminar flow on the surface of high-speed bodies has interested many scientists during the past thirty years. Figure 1

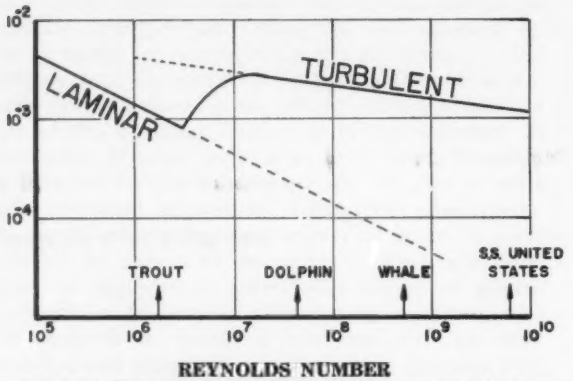


**Figure 1. Friction-drag coefficient of flat smooth rigid surfaces as a function of the Reynolds number.**

shows the generally accepted facts about fluid friction on smooth, flat, rigid surfaces. It plots the friction-drag coefficient for different values of the Reynolds number. The Reynolds number is a factor which depends on the length and speed of a body moving through a fluid and the viscosity of the fluid. In our case, the fluid is sea water and the Reynolds number is simply a measure of speed multiplied by length of the "bodies" in which we are interested—whether they are fish, speedboats or ocean liners. The arrows in Figure 1 indicate the approximate Reynolds numbers of the trout, the dolphin, the whale and the ocean liner *United States*. The drag coefficient is proportional to the actual drag divided by the wetted-surface times the square of the speed. Figure 1 shows two solid lines and a transition from one to the other. One solid line is marked "laminar" and refers to a fully laminar, smooth, turbulence-free surface flow. The other solid line is marked "turbulent" and refers to fully developed turbulence of the surface flow.

On smooth, flat, rigid surfaces the transition of the drag coefficient from laminar to turbulent begins at the transition Reynolds number $R=2.8\times10^6$ with the result that, for instance, at the approximate Reynolds number of the dolphin the drag of a slender, smooth, rigid body is approximately ten times as great as it would be if, by some means, fully laminar surface flow could be established under these conditions.

A general reduction of the friction drag by approximately 90 per cent would represent a scientific break-through with tremendous practical consequences. Much effort has gone into the study of suitable means to realize this breakthrough. The first, though only partial, success in this direction was the "laminar profile"—a particular shape of body which made it possible to keep the wall-near flow (that is, the flow close to the surfaces of the body or wings) laminar up to a Reynolds number approximately $15\times10^6$ and up to approximately two-thirds of the body length. The laminar profile today is used predominantly for high-altitude airplane wings, which meet the requirement of a comparatively low Reynolds number. It has led to approximately a 50 per cent reduction of the high-speed wing drag.

The typical laminar profile has its maximum thickness at two-thirds of its length. However, the dolphin has its maximum thickness at one-third of its length. Thus, it would seem that Nature has not used the laminar profile to keep the wall-near flow of the dolphin partially laminar. This becomes understandable when the accuracy requirements of laminar profiles near their maximum useful Reynolds number are considered. These profiles need to have the smoothness and the freedom from waviness of a concert piano—requirements that an animal simply cannot meet. Mouth, eyes, breathing hole, fins, injuries, scars, swallowed prey, pregnancy, etc., represent so many and so serious disturbances of the basic body shape that, in Nature, the laminar profile effect could not be retained for any length of time.

The laminar flow research had a second success when "distributed boundary layer removal" was found to be effective. Distributed boundary layer removal requires a porous hull and a pump that removes part of the wall-near flow by sucking it inside the porous hull. This principle has basically no limitation in Reynolds number; that is, it can be applied to the largest bodies and at the greatest speeds. Distributed boundary layer removal may some day play an important role in air transportation as a means for high-speed drag reduction; but, in water, the chances of applying this principle are slim. Inevitably, ocean water is muddy in places or full of microscopic life during certain seasons. These impurities would clog the porous hull and make the suction ineffective. So it is not surprising that the dolphin is not utilizing the principle of distributed boundary layer removal either—as even a superficial study of the dolphins' skin clearly indicates.

What, then is the dolphins' secret?

In 1938, I was granted German Patent No. 669897 entitled "Device for the Reduction of Friction Drag." The patent suggested that, for instance, fine narrowly-spaced wires should be mounted parallel to the flow and close to the surface. The patent explained that the friction in the narrow gaps between the wires would damp oscillations of the wall-near flow, thus suppressing the generation of turbulence and shifting the transition from laminar to turbulent toward greater Reynolds numbers. The test work in connection with this patent was discontinued on account of the war. After the war, in 1946, I came to America, following an invitation from the United States Navy to work at one of its research centers. During the ocean crossing I saw, for the first time, a school of dolphins and was fascinated by their performance. I started collecting literature about the top speed of the dolphin and

the output of its "muscle motor," and could soon prove by calculation that the dolphin has solved the problem of laminar flow. Thus, I decided to study the dolphin skin at the first opportunity.

This opportunity came in 1955 when a new oecanarium, called Marineland of the Pacific, opened its doors to the public at Palos Verdes, near Los Angeles, and Dr. Norris, leading biologist of Marineland, agreed to give me samples of dolphin skin. A cross-section of one of the many skin samples taken at that time is shown in Figure 2. This photograph shows the enlarged cross-section of the outer skin of a 7-foot white belly dolphin. The brown outer skin is approximately 1/16 inch thick. It is backed up by a yellow inner skin which is approximately ¼ inch thick and consists of tough tissues. The entire fish, including its head and its fins, is coated with the brown outer skin of almost constant thickness. Unlike the inner skin, the outer skin is so delicate that it can be scraped off with a finger nail. The surface layer of the outer skin consists of a highly pliable material. The inner layer of the outer skin contains a multitude of narrow ducts which are

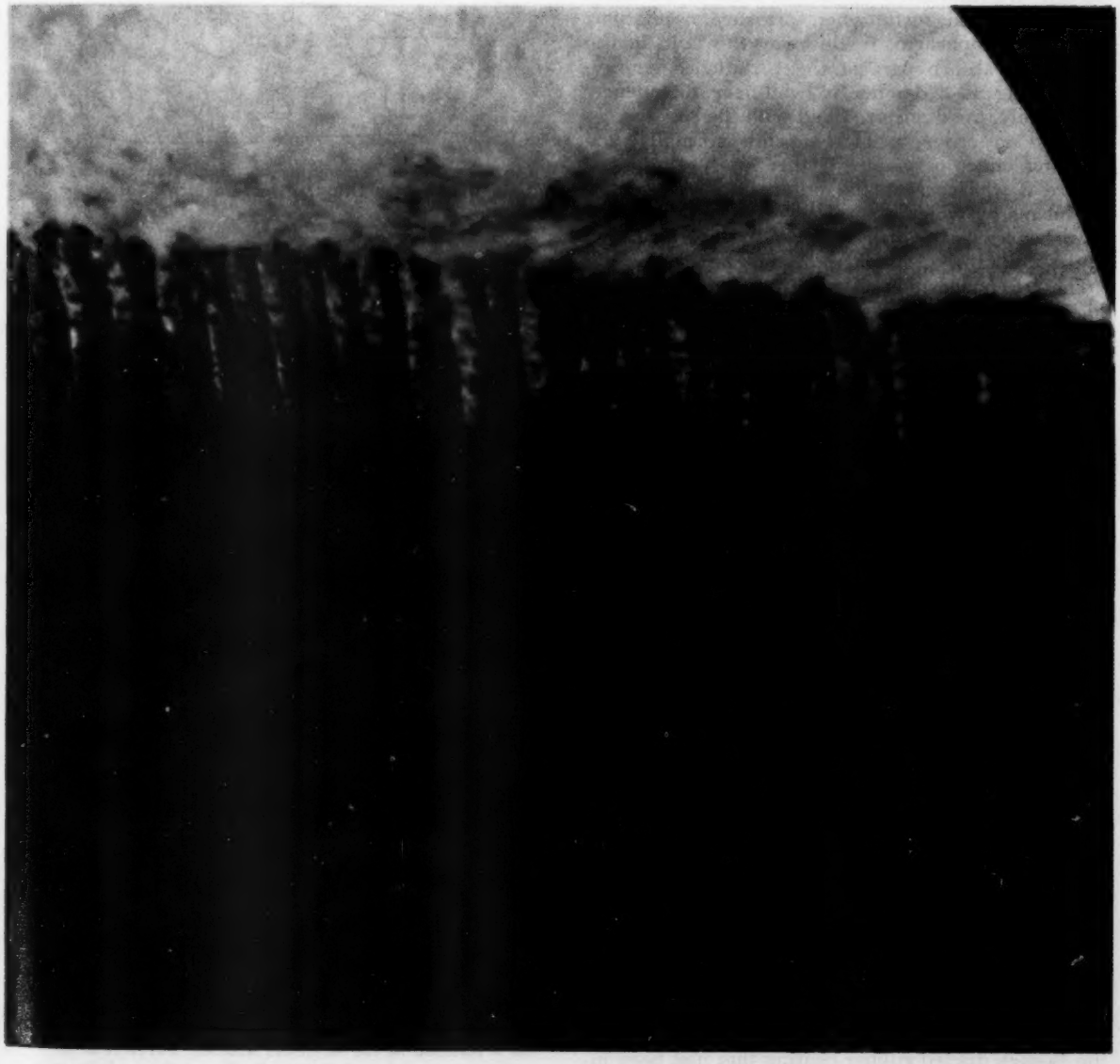

**Figure 2. Enlarged cross section of dolphin skin. The brown outer layer is approximately 1/16 in. thick and represents the drag-reducing coating of the dolphin.**

filled with a soft spongy material. The entire outer skin is waterlogged. It dries out, becomes brittle and turns soft again when put back into water. In the dry state, the outer skin weighs only one-fifth of its wet weight—an indication of its high water content.

I decided that the enlarged outer skin of the dolphin was probably a highly refined realization of the basic idea expressed in my 1938 patent. This skin consist in part of a smooth, pressure-sensitive diaphragm. The diaphragm can transmit the pressure oscillations that are caused at any one point of the surface when waviness or turbulence of the wall-near flow passes by. Underneath this diaphragm are fluid-filled ducts. The fluid in the ducts flows back and forth when pressure oscillations strike the diaphragm. In this way the fluid in the ducts will absorb part of the turbulence energy, thus acting as a damper of wall-near turbulence. Most likely, the ducts are filled with the soft spongy material in order to increase the normally low damping effect of water. If this interpretation of Figure 2 was correct, the outer skin represented the means by which damping of the wall-near flow disturbances was distributed over the entire surface of the dolphin.

The conclusions (1) that the performance of the dolphin indicates fully laminar flow, and (2) that its skin provides distributed dampings of wall-near flow disturbances greatly strengthened my confidence in what had so far been mostly a theoretical approach to the problem.

Preliminary tests with models were started at Coleman Engineering Company Inc., Torrance, California, in 1956 [3]. It was clear from the start that Nature's microscopic skin design could not be copied—just as, for instance, today's aircraft wings do not copy the design of bird wings, despite the fact that the bird wing incorporates all known desirable wing features. However, we gave our preliminary test models a coating which provided the three basic components derived from a technical interpretation of the dolphin skin; namely, the smooth pressure-sensitive diaphragm, the structure supporting the diaphragm and the damping fluid. By the end of 1956, the preliminary tests furnished, for the first time, measured evidence of the soundness of the principle of distributed damping. It was at that time possible, with the aid of a coating, to raise the transition Reynolds number 140 per cent, despite strongly adverse flow conditions and the very primitive design of the coating at this stage of the experiments. This preliminary result was so promising that it seemed to justify intensified research.

The intensified research led to convincing test results under more practical flow conditions by the end of 1958 [4]. Figure 3 shows the dimensions of the ⅛-inch ducted rubber coating that had been investigated at that time. The coating consisted of a 1/16-inch rubber diaphragm supported by a multi-

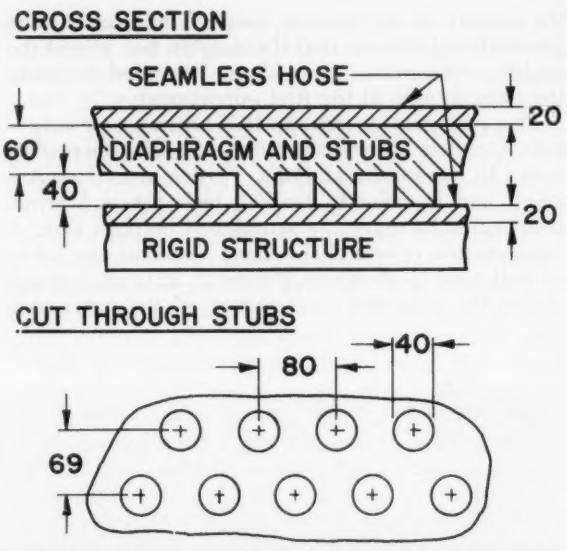


**Figure 3. The dimensions of the ducted rubber coating tested. (Dimensions in 1/1000 of an inch).**

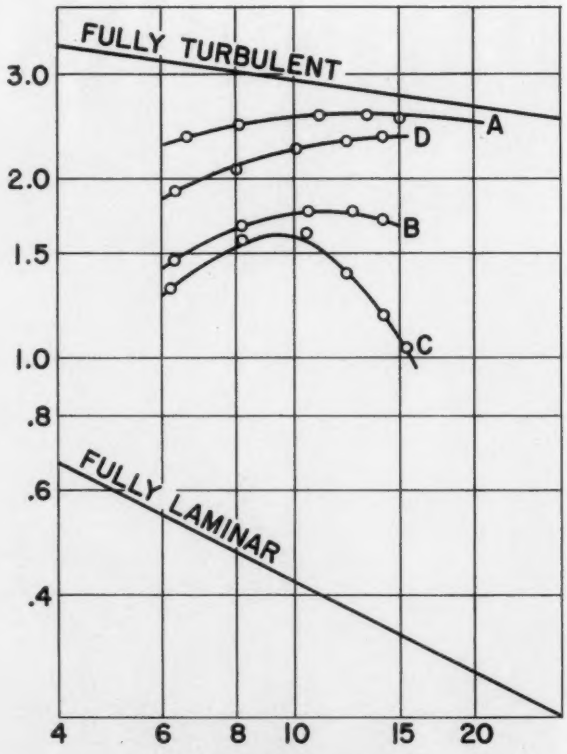


**Figure 4. The friction-drag coefficient of various models as a function of the Reynolds number. Curve A is the rigid reference model, and Curves B, C, and D are fully rubber-coated models with an elasticity module of the rubber: B= 250 p.s.i., C=100 p.s.i., D=70 p.s.i.**

tude of tiny narrowly-spaced rubber stubs. The space between the rubber stubs could be filled with damping fluids of various viscosities. Slender models 4 feet long were covered with this coating and towed at speeds up to 40 mph. Figure 4 shows the results of several drag measurements on such models in terms of the friction-drag coefficient over the Reynolds number. All models had exactly equal outside shape.

Curve *A* in Figure 3 refers to a model that had been machined out of solid nylon. Its surface was free from waviness and was polished to a high gloss. As was to be expected, its friction-drag coefficient at $15\times10^6$ Reynolds number was close to that of fully turbulent surface flow. The curves *B*, *C* and *D* in Figure 4 refer to models fully coated with rubber of various degrees of elasticity. The coating with an elasticity module of 100 lb. per square inch and 300 centistoke viscosity of the damping fluid, as shown by curve *C* in Figure 4, was most effective. At $15\times10^6$ Reynolds number, the drag coefficient of this model was 40 per cent of that of the rigid model. Also, the drag coefficient of the coated model was rapidly dropping near the top speed of the measurement, while the drag coefficient of the rigid model is known to be practically constant in this particular Reynolds number range.

## Hydrofoil Development

At the Third Annual International Symposium on Hydrodynamics held at the Hague, Netherlands, last month, the U.S. Navy, in conjunction with Dynamic Developments, an affiliate of Grumman Aircraft Engineering Corp., demonstrated an experimental gas turbine-powered hydrofoil boat, called the XCH-6, a forerunner of a large scale hydrofoil due for launching in 1961. Speeds up to 50mph have been reached by the 23-ft experimental craft in inland waters near The Hague and USA. The boat has a design capability of 80-mph and is powered by 1,000 hp GE Model 720 gas turbine weighing only 320 lbs. An outgrowth of XCH-6 will be a 90-ton ocean-going hydrofoil ship now under development for the Maritime Administration which will have a design speed of 60-80 knots. Like XCH-6 it will ride on triangular-shaped hydrofoils in open seas and on its conventional hull for harbor operation and docking. Primary power source will be a 20,000 G-E Model 240 gas turbine. The purpose of the XCH-6 experiment is to test scale models of giant hydrofoils to be used on larger craft. Specifically under test is the principle of supercavitation, discovered two years ago by Navy researcher Marshall P. Tulin. The supercavitation principle along with high rpm and high power-to-weight ratio of gas turbine engines have resulted in the present hydrofoil boat development. Larger boats of up to 300-passenger capacity are expected to follow in the next decade.

—From MARINE JOURNAL
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# THE UNITED STATES NAVY

## GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

## WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

## THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

"APPLIED MECHANICS REVIEW"

# *SIMULATION IN SCIENCE AND TECHNOLOGY*

**ACKNOWLEDGMENT**

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SIMULATION means similarity. It emphasizes particularly the imitation of the form or behavior of something. It is widely practiced in science and technology, and simulators have become essential tools in research, industry, and education.

In the sense of this paper a simulator is any physical system deliberately assembled and operated so as to provide useful information about some other system which is of interest. The simulator need not, and usually does not, physically resemble the system of interest, although it might in suitable cases incorporate within itself such actual components of the latter as are desired and available, even to the extent of those human operators who are essential links in the prototype system [1]. The term "simulator" is sometimes used in a much more restricted sense, being applied only to electronic differential analyzers, or, even more restrictively, to electronic differential analyzers operating in real (or "true") time. The current trend, however, is to use the term for such a variety of computing devices as solid and liquid electrically-conducting sheets, hydrodynamic fields, membranes, passive electrical circuits [2, 3], and for real-time and non-real-time digital computers [4, 5], and combinations of analog and digital computers operating in either real time or non-real time [6, 7].

Simulation serves three major purposes: problem solving, system design, and operational training. These are considered in order.

### PROBLEM SOLVING

Two general classes of problems are involved. On the one hand, given the characteristic coefficients (which may be nonlinear or variable parameter functions) and the equations of operation of a particular system, one simulates the system and operates the simulator to obtain the relationships between certain input and output variables. On the other hand, given the relationships between input and output variables and the equations of operation of the system, one simulates these relations and operates the simulator to determine the unknown characteristic coefficients of the system [8]. The first class of problems is the one most extensively treated by simulation. In fact, even the second class develops into a series of problems of the first class when trial-and-error methods are used to obtain the unknown characteristics of the system.

In problems of the first class, system characteristics are determined theoretically or experimentally, the equations of operation of the system are developed, and one of several possible simulation systems, whose characteristics and equations of opera-

tion are of the same form, or could be put into the same form, as those of the prototype system, is selected, set up, and operated. The applied inputs and measured outputs of the simulator are directly proportional to the inputs and outputs to be expected in the prototype system, the constants of proportionality (scale factors) being determined by the relative magnitudes of the units used for the known quantities in the two systems. When problems of the second class are treated in this manner, system characteristics are initially assumed and then readjusted in successive trials on the simulator until the simulator outputs match the prescribed outputs to the required accuracy.

*Hydraulic Simulators.* The identity of the mathematical relations between Stokes's hydrodynamic problem (*ca.* 1843) for an ideal liquid occupying a rotationally-accelerating prismatic box and Saint-Venant's torsion problem (*ca.* 1855) for a prismatic bar with the same cross section led Thomson and Tait (*ca.* 1867) to suggest that the torsional problem could be solved by simulating it hydrodynamically. It appears that some 68 years transpired before the results of an actual experiment were disclosed [9]. However, this analogy served as the forerunner of a long series of hydraulic simulators of various kinds for systems obeying the Laplace, Poisson, biharmonic, diffusion and compressible flow equations. Most of these simulators, in common with the Thomson Tait device, are more useful in a qualitative or intuitive study of a problem than in a quantitative study.

Rayleigh (*ca.* 1893) pointed out that the stream function for viscous flow in a thin sheet and the transverse deflection of a plate clamped along the same boundaries were solutions of the same biharmonic equation. Goodier [10] showed that all such fluid motions within rigid boundaries at rest or in uniform motion simulate distributions of plane stress in a plate with the same boundaries either free from stress or subjected only to uniform normal stress. No record appears of such a simulation being actually carried out.

The experimental phases of hydraulic simulation appear to have first received prominence around 1900. Two-dimensional Laplacian fields in thin-sheet viscous flow between glass plates were made visible by means of dye streaks. The experiments were for the purpose of studying lines of force in electrostatic and in magnetic fields, any variations in dielectric constant or permeability over the field being simulated by variations in the thickness of the flow space (obtained by cutting into a wax coating on one of the glass plates). This form of simulation has been developed recently to a high degree of efficiency by Moore in the form of "fluid mappers" [11, 12]. There appears to be no limitation on the Laplacian, the Poissonian, or combinations of Laplacian and Poissonian fields that can be simulated in two dimensions by fluid mappers, including variations in field properties. Simple wells may be provided as point sources or sinks of different strengths. Distributed sources or sinks (preferably the latter) are provided by "sand-beds" consisting of high-flow-resistance beds of fine nickel or copper shot through which viscous fluid (usually water to which a small amount of Methocel had been added to increase viscosity) percolates vertically downward from a horizontal sheet-flow over the bed (distributed sink). Not only may the thickness of the flow field be varied from point to point, but also impervious obstacles of various shapes and sizes may be inserted in it.

Instead of using sandbeds, a new method to produce uniformly distributed sources (or sinks) over an area is to use a solid plate which is moved slowly to either increase or decrease the separation between it and the glass plate above it [13].

The laminar flow of viscous fluid in the annular space between two cylindrical tubes eccentrically positioned simulates the torsion problem of a hollow cylindrical bar of the same cross section [14].

The relative ease with which one-dimensional steady-state and transient diffusion problems can be simulated by water flow has led to numerous applications of this analogy, one of the most common being heat transfer. In the "Hydrocal" [15], thermal resistance, thermal storage, and temperature, are simulated, respectively, by fluid friction in capillary tubes, fluid storage in vertical standpipes, and fluid levels in the standpipes. The simulation is approximate in that it represents a limited number of perfectly-conducting lumps of finite size, each at a uniform temperature, connected in series by thermal resistances of negligible thermal capacity, through which the entire temperature drop occurs. The more standpipes are provided the more closely is the actual continuous distribution of the thermal field simulated. This was the method selected for simulation of transient thermal effects in the nose-cone re-entry problem [16], of thermal diffusion in moist soils accompanied by alternate freezing and thawing [17], and of transient heat transfer in a cross-flow heat exchanger [18]. Nonlinear time-varying boundary conditions, variable physical properties of the system, thermal radiation, latent heat effects, and other variable or nonlinear effects may be simulated by varying standpipe area with height and with time, varying reservoir heights, providing variable leakage paths at various heights in the standpipes, varying the lengths of the capillary tubes with position and time, and providing switching valves between various standpipes.

The time-dependent forced motion of a piston forcing liquid into a standpipe of variable cross sectional area may be used to simulate creep and relaxation in real materials, such as prestressed concrete. Results from such hydraulic simulators

have been found to agree with actual creep and relaxation tests on high tensile steel wires [19].

Of recent interest has been a series of disclosures on the simulation of shock waves in transonic compressible flow by surface waves produced in towing a large model through water of ¼ inch depth [20, 21]. The analogy applies to a hypothetical gas for which the specific heat ratio is 2. The squares of the relative depths of the thin water layer disturbed by the passing of the towed model represent relative pressures in the two-dimensional "hydraulic gas" flow about a similar obstacle. The analogy was also applied to the study of pressures and Mach number in an ejector [22] and to high-velocity combustion [23].

*Membrane Simulators.* The thin stretched membrane with small transverse deflections also simulates two-dimensional Laplacian and Poissonian fields. Beginning with Prandtl's disclosure [24] that the shear stress function for a prismatic bar in torsion may be simulated by this means, soap films, rubber membranes, and surfaces of separation between immiscible fluids have been widely used for this purpose. A comprehensive account of such methods is given in [25] and a discussion of accuracy (2-3 per cent) in [26]. The rubber membrane was found to hold for quite large slopes [27], contrary to previous concepts. In the case of anisotropic media, it is possible in certain cases to reduce the problem to an isotropic one by a suitable transformation of coordinates, and the membrane analogy can be used [28]. Intuitively, it has been found advantageous to replace the fourth-order Lagrange equation for the deflection of thin plates by two second-order equations which represent membrane deflections [29].

An important use of the rubber membrane has been electron path determination in the dynamics of charged particles in electric fields, making use of rolling steel balls on the distended membrane. The rolling of steel balls in this instance is found inaccurate [30] and methods of simulating electric fields and space charges by rubber sheets have been developed so that electron trajectories may be found without actually using rolling balls [31].

The membrane could be combined with an electrical analogy. This was done in simulating the field of water about a drainage well in a porous soil [32], where the variable ground-water surface was represented by an adjustable rubber membrane while the water field beneath was represented by an electrolytic sheet.

Despite its inherently two-dimensional character, the membrane can simulate Laplace's equation in axially-symmetrical three-dimensional fields by subjecting it to a distributed force proportional to $1/r\,(\partial h/\partial r)$, where $h$=membrane height [23].

*Electrolytic Tank, Electrically-Conducting Solid, and Resistance Network Simulators.* An extensive bibliography on these devices is given in [34] and a comprehensive treatment in [2]. Because of their simplicity, convenience and capacity to provide quick answers such simulators have found much favor not only for general potential field problems, but also in numerous other applications involving various types of partial and ordinary differential equations. Considerable emphasis has been given in recent years to resistance network simulation, at times in combination with other devices. Examples include nonsteady incompressible flow about an oscillating wing with flaps [35], limit analysis of frames [36] and electron trajectory problems [37]. In combination with electronic memory elements and switches, a resistance network has been used to simulate Graetz's eigenvalue problem for temperature distribution in laminar flow through a pipe [38], as well as other partial differential equations. A unifying "cell principle" in the design of resistance network simulators leads to the representation of the Dirichlet, Neumann or Fourier boundary conditions on arbitrarily curved boundaries [39]. A combination of a deep electrolytic tank and a network of capacitors was developed for three-dimensional transient heat flow studies [49].

*Dynamical Analogies.* Since Nickle's paper in 1925 on the force-voltage analogy and Firestone's paper in 1933 on the force-current analogy, much discussion has ensued with respect to the relative merits of the two analogies. The problem has been recently re-examined [41] on the basis of reciprocity in the equivalent electrical circuits for magnetic transducers (ideal transformers) and electrostatic transducers (ideal gyrators). Presuming an equivalent circuit means element-by-element correspondence, the force-current analog only is shown to be valid. In this connection questions of duality in electrical and mechanical circuits have received attention [42, 43]. For the most part recent applications of dynamical analogies have followed standard patterns. Interesting applications of the force-current analogy are to the statics of an aerodynamically-heated wing [44] and to flexure-torsion of a celled tube [45]. Also a recent development is the simulation of rotating shafts by electrical "eight-poles," including support flexibility and gyroscopic moments on disks [46].

*Electronic Analog and Digital Computers.* The electronic differential analyzer, now commonly termed "electronic analog computer," or "electronic simulator," came into use as a problem-solving device in the early 1940's. Since then its use has greatly expanded and computers from simple "do-it-yourself" kits to room-filling multi-million dollar installations have become available. The fundamental unit of this computer is the very high gain (preferably "infinite") d-c operational ampli-

fier. With appropriate input, output and feedback circuits, numerous mathematical relations ("transfer functions") may be developed between the input and output voltages. Further operations on these relations may be made with multipliers and other non-linear function generators. Aside from computer stability problems and error considerations [47, 48], problem simulation is straightforward.

Current trends are in the direction of optimum programming [49], matrix programming [50], generalized integration [51], study of random processes [52, 53], experimental determination of system transfer functions [54], combined analog-digital machines [55], etc.

Since the advent of general-purpose electronic digital computers in the middle 1940's, the initial conception of them as strictly numerical analyzers has markedly shifted toward the more fundamental conception of them as simulators [56].

### SYSTEM DESIGN

Simulation techniques in system design lean very heavily on electronic analogue and digital computers. The simulation is usually carried out in several stages from the preliminary to the final design as new information becomes available from system and component tests, and as the actual "hardware" for use in the system is manufactured. Initial simulation serves to confirm or refute basic concepts. It also serves to establish optimum values of important system constants, leading finally to a large-scale simulation in which all major components affecting system performance are accurately simulated or actually included [1]. Examples of simulation in design are the Nike missile systems [57], a nuclear power plant [58], a free-piston engine [59], a distributed-parameter control system [60], a flight simulator [61], etc. The techniques are, to a large degree, those used in problem solving, except for the differences in viewpoint and scale of operations. Promising approaches to optimum system design include optimization by random search on the analog computer [62] and by nonlinear programming using gradient methods on high-speed digital computers [63].

### OPERATIONAL TRAINERS

Where a human operator is required to meet situations fraught with danger, where his decisions or actions might invoke such situations, or where the cost of training the operator with the actual equipment is prohibitive except for final checkout, simulators are used for operator training purposes under as realistic conditions as possible. An aircraft operational flight simulator consists of a replica of the cockpit interior, including a full complement of properly functioning instruments, an electronic analog or digital computer for real-time solution of the aircraft flight equations, hydraulic loading devices to simulate control column "feel" and to cause cockpit accelerations in roll, pitch and to some extent in vertical translation, sound systems to simulate engine, compressor, slipstream, hydraulic and other sounds, a television display of an airport runway and approach for realistic simulation of take-off and landing, etc. [64, 65]. Such simulators have been constructed not only for propeller and jet aircraft, but also for helicopters [66], nuclear power plants [67], battle radar trainers [68].

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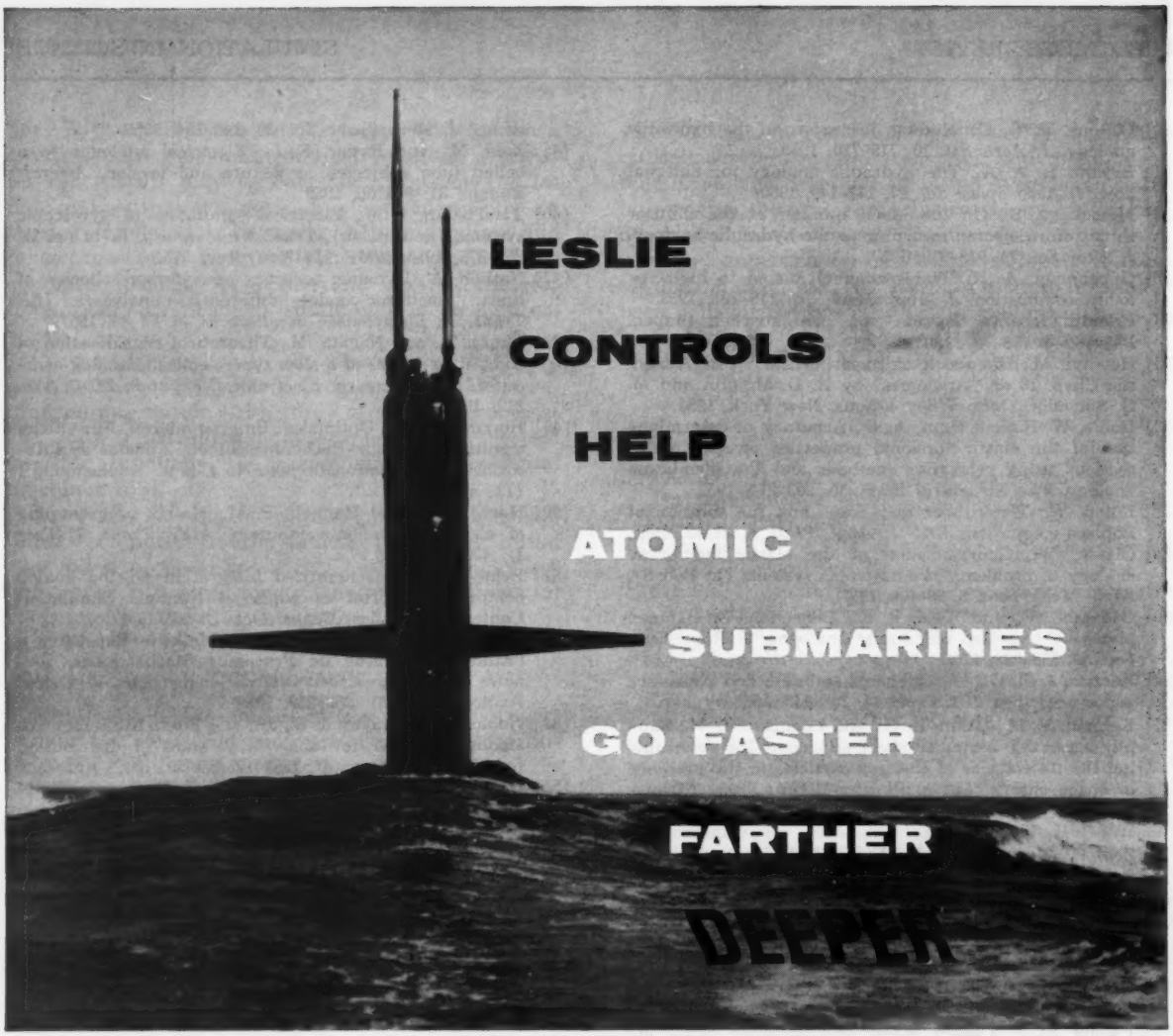


At sea with the fleet, on patrol or a cruise, there's no time or place for major repairs or replacements. That's why ships of the U.S. Navy as well as 95% of America's merchant fleet are Leslie-equipped. Almost all shipowners, operators and builders have learned to depend on Leslie controls to keep ships moving from port to port on schedule—without costly, time-consuming mishaps.

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LIEUTENANT E. M. AVALLONE, U.S.N.

# *QUALITY CONTROL*

**THE AUTHOR**

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*The*
*Normal*
*Law of Error*
*Stands out in the*
*Experience of Mankind*
*as one of the broadest Generalizations of natural philosophy—it serves as the guiding instrument in researches in the physical and social sciences and in Medicine, Agriculture, and Engineering — it is an indispensable tool for the analysis and the interpretation of the basic data obtained by observation and experiment*
*W. J. Youden, published in American Statistician Vol. 4, April-May 1950, p. 11.*

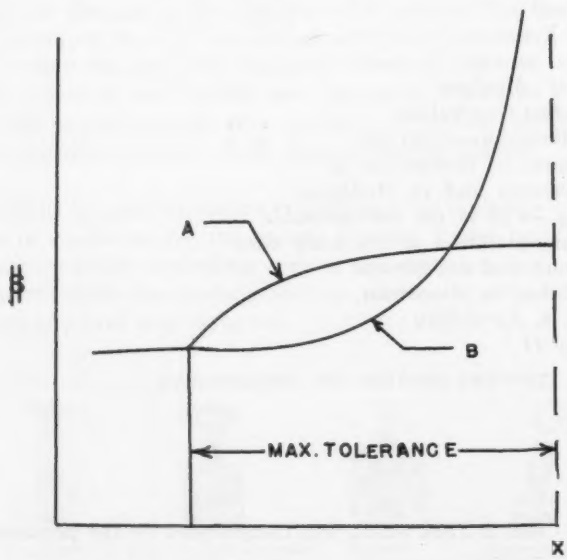
Control charts were first developed by Walter A. Shewhart at the Bell Telephone Laboratories in the period from 1924 to 1931.[1] While working on a problem in 1924 which was complicated by the presence

1. [2] page 91.

of random variation, he came to realize that the problem was statistical in nature. In observing the data, he noticed that there were two types of fluctuations present. One set of fluctuations was natural and unavoidable, but periodically fluctuations would appear which were unnatural.

In attempting to analyze the process producing the data, Dr. Shewhart struck upon a brilliant idea. A complete study of the natural variations of the data could be made. From this study natural variations of the data could be established, so that fluctuations appearing beyond these limits would indicate a possible change in the underlying process. There followed a great deal of research with data taken from actual plant processes. Various methods of analyzing the data were tested. The final system was presented in a book published by Dr. Shewhart in 1931 entitled "Economic Control of Quality of Manufactured Product."

Before considering the quality control charts, I feel that a discussion of the reason for manufacturing to specification should be discussed. We are aware of the fact that a manufacturing process generally has in mind a specific dimension which is desired in a completed product. Due to natural variations in the manufacturing process, a specific dimension can not be attained, so manufacturers produce items within certain preassigned tolerances. Let us consider the worth of the product in terms of dollars, where the closer the product is to the dimension desired, the more it is worth. In conjunction with this, we must consider a cost curve, where the closer to the specific dimension we require our output, the higher the cost. We can show both these ideas graphically where curve A is the market value of the product and curve B the manufacturing cost.




On the basis of the curves, a point can be determined at which it is most profitable to manufacture. In other words, there is an optimum quality having tolerances where production should be held, and any departure from these tolerances will decrease profits. It should be apparent that if curve B never crosses curve A that you had better not go into business. The curves are hypothetical in character, but serve to illustrate that economics dictate the quality of the product to be produced, and that deviation from the assigned tolerances mean a loss of profit.

From this simplified approach can be derived an economic factor which requires some sort of control to prevent the delivery to a consumer of a product beyond the specified limits. Control can be achieved in two ways. The first is to hire excellent personnel, use only the best raw materials, and provide adequate supervision, and inspection. Your cost of production will undoubtedly be increased, but more important is the present state of our labor force. Unions have so regimented labor that competition between big (or small) industries no longer depends on the quality of personnel. It is important to note that no improvement in the manufacturing process results from this approach. Thus, this first method, although a solution, would only be a temporary one for competing plants would soon follow your lead. The second solution is that proposed by statisticians: that is the application to the production process of statistical controls — in short, the control chart. Although this second approach will also be expensive and practiced by all competing industries, it will lead to permanent improvements in the manufacturing process. In addition, scientific analysis of the manufacturing process, is cumulative, for one researcher starts building at the point where another leaves off. The process is in a sense a dynamic one in that continual advancement in quality is the result.

At this point we can stop to summarize the brief introduction presented thus far. We have decided to go into business to produce a particular item, and have determined the tolerances to which we must manufacture for the maximum profit. To maintain these tolerances we have decided to use a controlled system. A definition of a controlled system by Shewhart is as follows: "A phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future. Here it is understood that prediction within limits means that we can state, at least approximately the probability that the observed phenomenon will fall within the given limits." [7] To consider a controlled process two types of errors must be defined, assigned and unassigned errors. Assigned errors are those which can be traced to a defective machine or workman, while unassigned errors are those due to the natural distribution about some mean attained in a manufacturing pro-

cess. Some remedial steps can be taken to eliminate assignable errors, but nothing can be done to eliminate the unassignable errors. Therefore, if a detailed study of the unassignable errors is made, and limits determined, any variation in the product beyond the established limits may be due to the natural frequency distribution, but will probably be due to some traceable error.

At this point it will be assumed without proof that the unassignable errors have a normal distribution about some mean value (the desired specification). This is an assumption used throughout the quality control field. Such an assumption may appear to be a bold one, but rather lengthy proofs of its validity have been presented in [1,2]. The discussion that follows is based on such a normal distribution. We must now establish the limits within which the product may vary, and yet remain acceptable. Whenever possible, such limits should be subject to physical measurement and expressed numerically.

In developing the control chart, a number of terms and definitions must be presented. Many of these terms are familiar to statistics, while some are described as particularly useful in quality control work.

*Central tendency*—what single value within the range of observations best typifies the observations.

*Dispersion*—how widely do the observations differ among themselves.

*Skewness*—to what extent does the dispersion on the two sides of some central value depart from symmetry (i.e. lack of symmetry).

*Kurtosis*—to what extent is the dispersion accounted for by unusually large deviations.

*Parameter*—refers to the population value if an infinite number of measurements are made.

*Statistic*—refers to a sample value from a reasonable number of measurements.

Before continuing, a brief discussion of parameter and statistic seems appropriate. As an example, consider yourself having been assigned the task of computing the average height of a mature man. You could measure the height of all the mature men in the world, and compute the average. This result would be approaching a parameter in that you were approaching an infinite number of measurements. The more measurements you take the more accurate your resultant average will be. Of course taking the measurements of all mature humans is a hopelessly large task.

Now consider a more reasonable assignment. Determine the average height of a mature man by measuring one hundred men of each nationality. Select your candidates randomly to get good data.

Your result is a statistic since you have sampled the population. Of course your answer here is probably a good one, and should be close to your previous answer. In industry small samples are taken, for it would be expensive to measure each item produced. The analyses of the small samples lead to statistics rather than parameters. Following is a table which gives definitions for the symbols to be used. It should be kept in mind that those items appearing in the parameter column are merely definitions, for you seldom if ever, measure an entire population or product. The actual mechanics of computing these terms is illustrated in the tabulation on the warp-breaking strength of eight specimens of cotton cloth in the example hereafter.

| Moment | Statistics | Parameter[2] |
|---|---|---|
| **First** (about zero) | $x=\bar{n}$ | $u$ |
| **Second** (about the mean (variance)) | $S^2=m_2$* | $u_2$ |
| **Third** (about the mean) | $m_3$ | $u_3$ |
| **Fourth** (about the mean) | $m_4$ | $u_4$ |
| **Relative skewness** | $a_3=m_3/m_2^{3/2}$ $=m_3/s^3$ | $\alpha_3=u_3/u_2^{3/2}$ $=u_3/s^3$ |
| **Relative kurtosis** | $a_4=m_4/m_2^2$ $=m_4/s^4$ | $\alpha_4=u_4/u_2^2$ $=u_4/s^4$ |

* $E(s^2)$=average of repeated samples of n observations.[3] $=(n-1/n)\sigma^2$

The terms skewness ($a_3$) and kurtosis ($a_4$) are used to describe the non-normality and peakedness of the sample distribution. For the normal distribution $a_3=0$ and $a_4=3$. It should be kept in mind that these are relative values which are used as a comparison with the normal. Perhaps the only safe statement to make is that if $a_4=3$, the distribution is "over-fourth-momented" in comparison with the normal. Similar caution must be exercised in interpreting the value $a_3$. In describing a distribution the symbols $\gamma_1$ $(=a_3)$ and $\gamma_2$ $(=a_4-3)$ are sometimes used. The term coefficient of variation "V" is used quite a bit and its definition, $V=\left|\frac{\sigma}{\bar{x}}\right| 100$ shows that it is exactly equal to the definition appearing in Evans's The Atomic Nucleus (chapter 26) FSD×100. Control charts sometimes are plotted with the range (dispersion) instead of standard deviation plotted as the ordinate.

$$\text{Range}=\text{highest value}-\text{lowest value}$$

An unbiased estimate of $\sigma$ can also be obtained from the range R

$$\sigma=E(R/d_2)$$

$E(R)$ is expected value of the range. Generally of samples taken it is the mean range.

$d_2$ is tabulated value dependent on the sample size

$\sigma$=standard deviation

2. [1] page 23.
3. [1] Formula 6.1, page 60.

A sample calculation using the terms described will best illustrate their use:

*Warp-breaking Strength of Eight Specimens of Cotton Cloth*[4]

| x Breaking Strength, Lbs. | $X=x-\bar{x}$ | $X^2$ | $X^3$ | $X^4$ |
|---|---|---|---|---|
| 57 | −8.75 | 76.56 | −669.922 | 5,861.81 |
| 65 | −0.75 | 0.56 | −0.422 | 0.3164 |
| 65 | −0.75 | 0.56 | −0.422 | 0.3164 |
| 66 | 0.25 | 0.06 | 0.0156 | 0.0039 |
| 67 | 1.25 | 1.56 | 1.9531 | 2.4414 |
| 67 | 1.25 | 1.56 | 1.9531 | 2.4414 |
| 68 | 2.25 | 5.06 | 11.3906 | 25.6289 |
| 71 | 5.25 | 27.56 | 144.7031 | 759.6914 |
| x=526 | 0 | 113.5 | −510.75 | 6,652.656 |
| $\bar{x}$=65.75 | 0 | $m_2$=14.19 | $m_3$=−63.84 | $m_4$=831.58 |

Variation $\Sigma x^2=113.5$

Variance $m_2=s^2=113.5/8=14.19$

Standard deviation $s=\sqrt{14.19}=3.767$ pounds

$$a_3=\frac{m_3}{s^3}=\frac{-63.84}{54}=-1.18$$

$$a_4=\frac{m_4}{s^4}=\frac{831.58}{204}=4.06$$

$$\bar{x}=65.75$$

$$\sigma^2=\frac{n}{n-1}s^2=8/7(14.19)=16.23$$

$$\sigma=4.04$$

$$\bar{x}\pm\sigma=65.75\pm4.04$$

Now with the tools in hand an extensive sampling of a product can be made, and the mean and standard deviations are computed assuming that the unassigned error distribution is normal. A knowledge of the standard deviation combined with the desired tolerances provides enough information for making up a control chart of the following form.

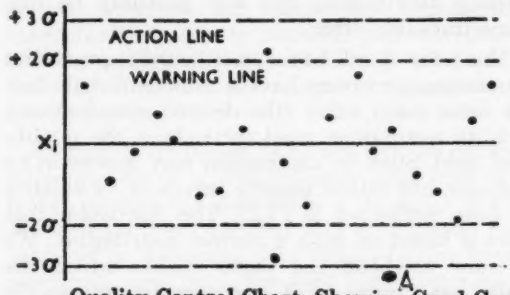
The upper and lower limit lines are determined by the desired tolerances and the standard deviation or as shown in the following table.

*Rejection Rates at Given Values in Terms of Standard Deviation*

| Values | Rejections, per cent |
|---|---|
| $\sigma$ | 32. |
| $2\sigma$ | 4.6 |
| $2.6\sigma$ | 1.0 |
| $3\sigma$ | 0.27 |
| $4\sigma$ | 0.006 |

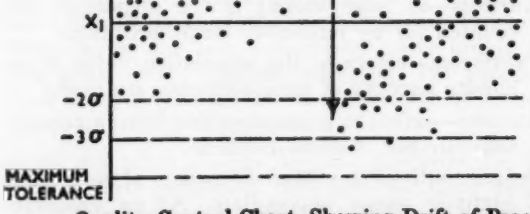
There are three general forms of the control chart used. The first is shown above with standard deviation as ordinate, and sampled points are plotted chronologically to determine the trend of the product being produced. It is more convenient generally to plot $\bar{x}$ or the range R as ordinate and to plot these values of the sampled product chronologically along the abcissa.

As an example of the use of control charts two different quality control charts are shown.




—Quality Control Chart, Showing Good Control.

The first chart shows good control with a random distribution about the mean. Point A on the chart might be due to an unassignable error or to the random distribution, but at any rate should be investigated to attempt to determine the cause. Such an investigation may yield some fault or defect in the production process before it becomes serious enough to affect a large portion of the output.




—Quality Control Chart, Showing Drift of Process.

In the second control chart shown the process is in poor control. Even after a correction was made to correct the definite drift in output the products again show a drift towards unsuitable product output. The production process in this case should be thoroughly investigated to determine the cause. In determining the chronological points on the quality control chart samples of the parent population must be taken. Two reasons for sample testing are, one, that it saves money, and two, that it is absolutely necessary where tests destroy the piece.

Perhaps the next logical question is — once a control chart has been established, how large a sample must be taken to be representative of the parent population or total output of product? I don't intend to discuss what percentage of a par-

4. [1] pages 9, 11.

ent population must be sampled to be representative of the population, for this is another field of statistics entirely. Perhaps the two points to remember are that a random sampling must be made which is representative of the parent population. In one instance [6] it can be shown that, of a population of 1000 items with a mean of 60 and a standard deviation of 10, a *random sample* of 300 gave excellent agreement. While in other instances,[5] 5 out of 50 is far too few on which to make a decision, while 1000 out of a lot of 10,000 items is probably much more than is needed for a sound decision on the lot. Thus, once the control chart is established the next step is to determine how large a sample, randomly selected, will be representative of the product. In random sampling, it must be remembered that it would be much too easy to take all the samples from one box or one section, and care must be exercised to insure the randomicity of the sample. An interesting example of sampling is given in [2].

100 castings were taken from a box containing 3000. Of these 100 castings, 25 were found to be defective. So the remaining 2,900 castings were sorted. How many more defectives were found? Only 4. The question is: was the sample of 100 drawn at random from the 3000? This example is not an isolated case in industry.[6]

Remember that the gross size of the sample is far more important than the percentage the sample is of the lot. In the case of 10 percent: 5 out of 50 was too small, while 1000 out of 10,000 was too large a sample.

To summarize once again, we are in business, have determined tolerances for our products, have made an investigation of the product to determine the mean, range and standard deviation of the natural frequency of the unassignable errors, assuming the distribution to be normal, and have determined sample sizes to represent the parent population. Our system as it stands should be functional and the control chart should give us early warning of difficulties ahead. The only point in our development which could be troublesome, and perhaps disastrous, is the assumption that the unassignable errors have a normal distribution. Apparently this point is a debatable one, for [1] and [2] discuss it at great length while [3] and [6] are devoted entirely to this subject. In order to clarify the assumption, I will follow the arguments presented by [6].

Using $\bar{R}/d_2=\sigma$

$\bar{R}/d_2\sigma=1$ for a normal population, since $d_2$ is calculated for a normal population.

Consider 5 populations with their appropriate measure of departure from normality.

$\gamma_1=a_3=0, \gamma_2=a_4-3=0$ for normal population.

| Form | Equation | range | $\gamma_1$ | $\gamma_2$ |
|---|---|---|---|---|
| (a) Exponential | $p(x)=e^{-x}$ | $0<x<\infty$ | 2 | 6 |
| (b) $x^2_4$ | $p(x)=\frac{1}{2}x^2e^{-x}$ | $0<x<\infty$ | 1.12 | 2 |
| (c) $x^2_3$ | $p(x)=1/6x^3e^{-x}$ | $0<x<\infty$ | 1 | 1.5 |
| (d) Double exponential | $p(x)=\frac{1}{2}e^{-\lvert x\rvert}$ | $-\infty<x<\infty$ | 0 | 3 |
| (e) Logistic | $p(x)=\frac{e^{-x}}{(1+e^{-x})^2}$ | $-\infty<x<\infty$ | 0 | 1.2 |

The values of $R/d_2\sigma$ for these five populations are given below:

| Parent Population | Sample size-n | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| a | 0.886 | 886 | 891 | 896 | 901 | 906 | 911 | 916 | 919 |
| b | 0.959 | 959 | 961 | 963 | 964 | 966 | 967 | 968 | 969 |
| c | 0.969 | 960 | 970 | 971 | 972 | 973 | 975 | 975 | 976 |
| d | 0.940 | 940 | 952 | 966 | 980 | 993 | 1.006 | 1.017 | 1.027 |
| e | 0.978 | 978 | 982 | 987 | 993 | 998 | 1.004 | 1.009 | 1.014 |

Notice that considerable differences occur and that no universal rule would appear to be applicable. In almost all cases the value of the standard deviation obtained by using $d_2$ (which has been derived for a normal distribution) is smaller than it should be for a normal distribution.

From the table it can be determined that in the majority of cases, and especially for small samples, the use of normal-curve factors will tend to underestimate the standard deviation. Increasing the size sample is not necessarily a guarantee of increased accuracy, and in some cases can make the estimate of $\sigma$ more inaccurate. The results shown here are in general agreement with those derived in [1] and [2] by different methods. It is generally accepted that the assumption of a normal distribution for the unassigned errors leads to a smaller value of $\sigma$, thus closer limits on the control charts. In engineering "lingo" the approximation is on the safe side for populations which are not badly skewed. Caution should be exercised in blindly assuming a distribution is normal, and applying the parameters for a normal distribution. Moore offers a simple test . . . "An increase in sample size will effect some improvement, but will always leave some error if the variability is estimated from the mean range in the available samples, using the $d_2$ factors from the normal distribution. There is therefore, a strong case at the start of a scheme for estimating the variability both by using the standard deviation in the samples, and the range in the samples. If the two methods give similar results it is an indication that normal distribution theory is reasonably appropriate, but if they differ, the standard deviation itself should be used, and as large a sample as feasible should be employed for the chart."[7]

5. [2] page 298.
6. [2] page 298.
7. [6] page 178.

A simple numerical example will serve to illustrate the use of the control chart. The problem concerns the weight of ingots, and the percent of yield in rolling. Molten metal from the open-hearth furnaces is poured into ingot molds, which are removed after a sufficient period of cooling. The ingots are reheated and rolled into bars of specific size. There is some unavoidable loss, but unless the weights of the ingots are well controlled, there may be a considerable loss in the process.

Control charts were used to study the weights of the ingots for a certain type of steel. In order to avoid as much multiple cut loss as possible, the ingot had been designed to weigh 5300 pounds. Control charts showed that the average ingot weight was 6520 pounds, or 320 pounds above the desired average. The range was determined to be 190 pounds, and in some cases as high as 440 pounds. Points were determined using four randomly chosen ingots from a single heat from an open hearth furnace as representative samples.

In this case, determination of the cause was rather simple. Two suppliers were manufacturing molds for the ingots. Investigation showed that both suppliers were making molds over-size in dimension. After a discussion with the mold suppliers, and with new molds, a check was made of the ingots again. The average over-weight had decreased from 320 pounds to 190, with not quite so large a variation from lot to lot. The average range was down from 190 pounds to 134 pounds. This was still not good enough.

Modifications in the production process were made, discussions were held with the production crews, and another conference with mold suppliers was held. A final average weight of 5296 pounds has been attained with a variation from one ingot to another of 82 pounds. The entire change took one year to accomplish, but at the going price of steel (1946) a savings of 175,000 dollars per year was realized.

It is interesting to note that bonuses paid to foremen in this case made them particularly enthusiastic in co-operating to attain the desired results.[8]

The thumbnail sketch of a quality control chart is now complete. In general, construction and application can be outlined in several brief steps:

1. Decide what to manufacture, and if it is economically feasible.
2. Establish tolerances at which to manufacture.
3. Analyze the unassigned errors assuming a normal distribution.
4. Determine the size sample needed to represent the parent population.
5. Lots of luck!

8. [9] pages 6-14.

## Appendix I

Values of $d_2$ derived for a normal distribution by E. S. Pearson, "Biometrika" Vol. 24, pp 404-417 Nov. 1932. Can be used as described in paper or see bottom page 903 [8].

| Sample size, n | $d_2$ | Sample size, n | $d_2$ |
|---|---|---|---|
| 2 | 1.128 | 24 | 3.895 |
| 3 | 1.693 | 25 | 3.931 |
| 4 | 2.059 | 26 | 3.964 |
| 5 | 2.326 | 27 | 3.997 |
| 6 | 2.534 | 28 | 4.027 |
| 7 | 2.704 | 29 | 4.057 |
| 8 | 2.847 | 30 | 4.086 |
| 9 | 2.970 | 35 | 4.213 |
| 10 | 3.078 | 40 | 4.322 |
| 11 | 3.173 | 45 | 4.415 |
| 12 | 3.258 | 50 | 4.498 |
| 13 | 3.336 | 55 | 4.572 |
| 14 | 3.407 | 60 | 4.639 |
| 15 | 3.472 | 65 | 4.699 |
| 16 | 3.532 | 70 | 4.755 |
| 17 | 3.588 | 75 | 4.806 |
| 18 | 3.640 | 80 | 4.854 |
| 19 | 3.689 | 85 | 4.898 |
| 20 | 3.735 | 90 | 4.939 |
| 21 | 3.778 | 95 | 4.978 |
| 22 | 3.819 | 100 | 5.015 |
| 23 | 3.858 | | |

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"JOURNAL OF THE FRANKLIN INSTITUTE"

# *NEW GYROS FOR OUR SUBMARINES*

**ACKNOWLEDGMENT**

*Originally delivered as a lecture at a joint meeting of Philadelphia Science Teachers Association and The Franklin Institute by the author, Frederick D. Braddon, it appeared in "Journal of the Franklin Institute" in August 1960. It is reprinted from that issue of "Journal of the Franklin Institute."*

ON EVERY NAVAL vessel one will find an instrument known affectionately as the Gyro. This is the compass on which the ship depends to guide it on its way. Each man aboard knows that his safety and his mission depend upon this Gyro every minute of the day. It functions unattended and incessantly for months on end. It is the central datum to which the ship is steered, and to which all navigation, surveillance and ordnance functions are referred. The Gyro is not a conspicuous instrument, for it is small and quiet and is generally installed in a protected area deep within the vessel. It requires only electrical connections for its operation. Its output information is transmitted electrically to the remote navigation, surveillance and ordnance stations which need to know true-north and the zenith. This equipment is technically designated as the ship's Master Gyro Compass.

Many forms of gyro compass have been developed and employed by the Navy since the first installation on the *U.S.S. Delaware* in 1911. Changing requirements and changing technology have resulted in a succession of designs that have progressively led to improved accuracies, size reduction and a high degree of operating reliability. It is the purpose of this talk to describe the two currently manufactured Navy type compasses known as the Mark 19 and Mark 23 which are in wide operational use.

The origin of the Mark 19 dates back to World War II when we were confronted with the problem of precisely stabilizing and directing a high resolution shipborne radar designed for aircraft surveillance and air traffic control on carriers. We were amazed to discover the inadequacy of existing shipboard gyro compasses and stable elements for this purpose. Gyro compass accuracy was reasonably adequate for navigation, but transient perturbations in the output data hindered its use for azimuth

stabilization. The stable elements lacked vertical accuracy due to instrumental errors caused by gyro friction, mass shift and inadequate compensation of maneuvering and seaway accelerations. A comprehensive study was initiated to analyze this problem from which evolved the concept of a unitary three-axis gyroscopic element to replace the two separate instruments for azimuth and vertical indication.

Information was collected on the various forms of gyro compass and gyro vertical which were in general use in 1944, or which had been previously developed to the point of successful operation. We catalogued the detailed design and operating characteristics of these equipments under the headings listed in Figure 1. From these data we attempted to analyze and evaluate the theoretical and practical aspects of each design feature. On this basis we established the initial specifications for what was to become the MK 19 Gyro Compass. This tabulation further indicated that all the gyro compasses used gyros with a *horizontal* spin axis. Figure 2 shows that Sperry and Brown used a single gyro in the meridian plane, while Anschutz and Arma used two horizontal gyros linked to subtend the meridian plane. All the gyro verticals (sometimes referred to as stable elements) used a single gyro with a *vertical* spin axis. At this point a very significant observation was made. *The most precise level reference on a ship is the level attitude of the spin axis of the gyro compass.* Because of the extreme freedom of suspension of the gyro compass about the vertical axis, the gyro is free of perturbations in level. The gyro compass was therefore capable of more accurate indication of tilt in the meridian plane than any of the gyro verticals. From this observation it was deducted that an identical gyro with horizontal spin axis slaved 90° from the meridian gyro, as shown in Figure 3, would sense tilt

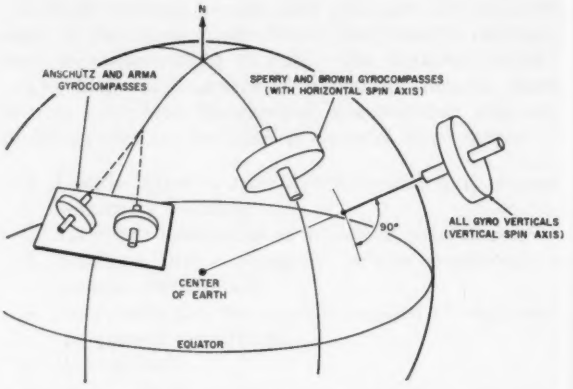



**Figure 2. Gyro arrangements for azimuth and vertical determination.**

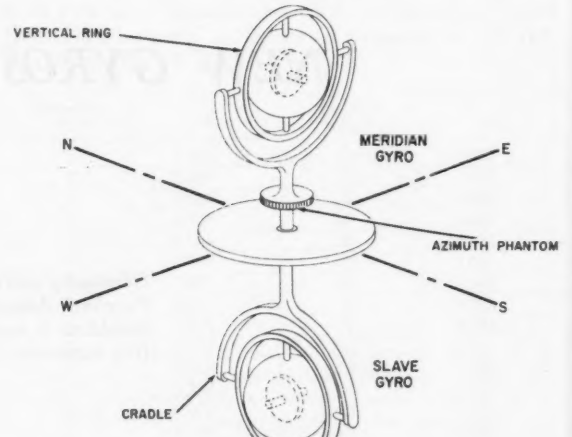



**Figure 3. Concept of unitary three-axis stable element.**

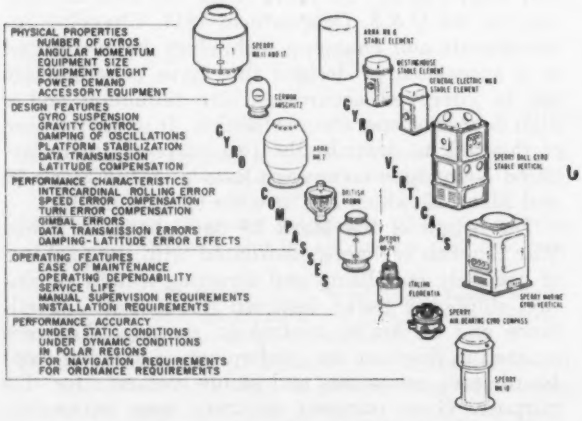



**Figure 1. Evaluation of gyro compasses and stable vertical equipment as of November, 1944.**

in the E-W plane with equal precision. Two intersecting horizontal lines thus define the horizontal plane to establish a zenith reference and the north seeking control of the meridian gyro continued to point its spin axis to true north. The MK 19 concept thus evolved as a precise and compact single instrument to replace the separate indicators. We originally called this instrument the "Zenith Meridian Indicator," and later conformed to Navy terminology using the designation "Gyro Compass Equipment Stabilized MK 19." This title has tended to de-emphasize the vertical indicating capability of the instrument.

As the result of this study and extensive experimentation and prototype manufacture, the present MK 19 Mod 3 design was established having the basic features listed in Figure 4. The idea of the composite vertical and azimuth indicator, the use of electrical methods of applying gravity coupling,

BASIC DESIGN FEATURES OF MK19 GYRO-COMPASS

1. TWO 2° OF FREEDOM GYROS, HORIZONTAL SPIN AXIS
2. GYRO SUPPORT BY FLUID EMERSION.
3. NEUTRAL BUOYANCY AND BALANCE OF GYRO UNITS.
4. GYRO CONTROL BY ELECTRIC TORQUERS.
5. LEVEL SENSING BY ACCELEROMETERS.
6. SHIP SPEED COMPENSATION BY GYRO TORQUING.
7. DESIGN SYMMETRY IN ALL MECHANICAL STRUCTURE.
8. PORTABLE INTACT THROUGH THE STANDARD SUBMARINE HATCH.
9. SELF CONTAINED SHOCK MOUNTING.

**Figure 4.**

and ship speed compensation by gyro torquing were all radical innovations.

Before describing the design characteristics of this compass, it is well to review the elementary principle of operation of the gyro compass that slaves it to the Earth and gives it the ability to automatically align itself to true north. A gyro compass serves to indicate the local meridian. Referring to Figure 5, the meridian plane is defined by two intersecting lines: (1) the axis of rotation of the Earth, and (2) the plumb-line at the ship's location. We use a gyroscope to sense the rotation of the Earth. On this gyro we mount a pendulum, liquid in containers, and accelerometer, or a spirit level to sense the attitude of the gyro to the gravity vector. As the Earth turns under the gyro, which tends to remain fixed in reference to the stars, the spirit level detects a tilt. In the MK 19 and MK 23, an electrical signal is derived from this level and an electrical torque applied to direct the gyro toward the meridian. The gyro thus nulls on the horizontal

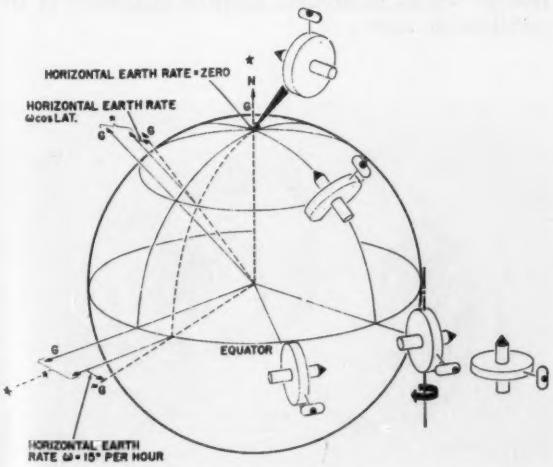



**Figure 5. North-seeking principle of the gyro compass.**

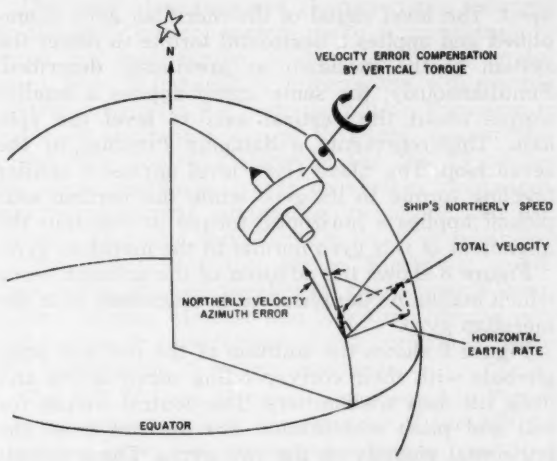



**Figure 6. Northerly speed azimuth error.**

component of Earth rotation to settle in the meridian plane. A natural error in azimuth indication results from the northerly velocity of the ship. The instrument can sense only the total angular velocity of the Earth and ship. Figure 6 shows this effect to cause the gyro to settle to the west of the meridian for northerly transits. In all previous types of gyro compass, the gyro spin axis was deflected from the meridian by a relatively large amount as a function of the ship's speed, heading, and latitude. This error was computed and corrected in the output data. As a result, perturbations in velocity log data caused instantaneous transients in the output data. In the MK 19 and MK 23 equipments, a vertical torque proportional to northerly speed is applied electrically to tilt the gyro at a rate equal to ship's northerly velocity. This control completely compensates the northerly speed error, smooths the effect of rough velocity data, and maintains the gyroscopic element fixed in the meridian plane.

Without too much detail, Figure 7 shows schematically the composition of the MK 19 Stable Ele-

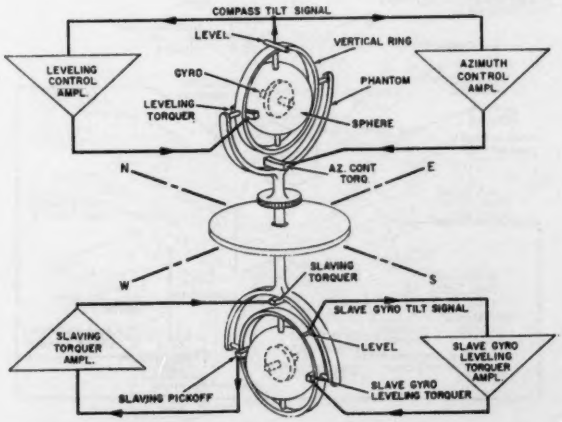



**Figure 7. Gyro leveling and azimuth control.**

ment. The level signal of the meridian gyro is amplified and applies a horizontal torque to direct the system to the meridian as previously described. Simultaneously, the same signal applies a smaller torque about the vertical axis to level the spin axis. This represents a damping function in the servo loop. The Slave Gyro level applies a similar leveling torque to its gyro while the vertical axis pickoff applies a horizontal torque to maintain the alignment of this gyro normal to the meridian gyro.

Figure 8 shows the addition of the azimuth servo which maintains the phantom in alignment with the meridian gyro.

Figure 9 shows the addition of the roll and pitch gimbals with their corresponding servo drives and deck tilt data transmitters. The control signals for roll and pitch stabilization are derived from the horizontal pickoffs on the two gyros. These signals are necessarily transformed from terms of E-W tilt and N-S tilt to the corresponding roll and pitch values by use of an electrical resolver on the azimuth drive.

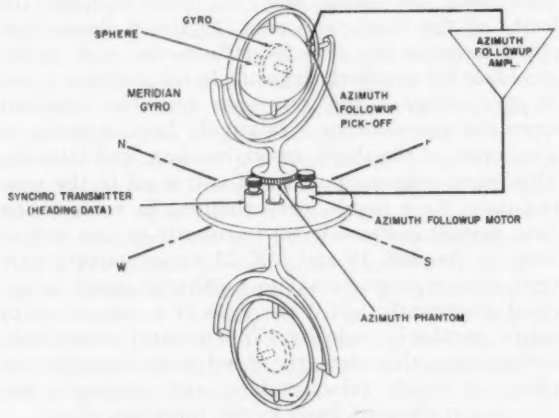



**Figure 8. Azimuth phantom servo drive.**

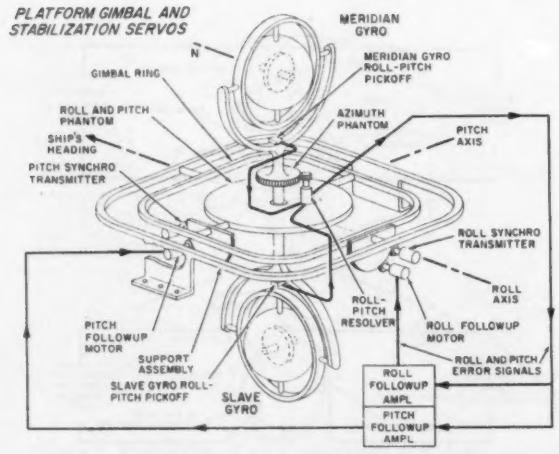



**Figure 9. Platform gimbal and stabilization servos.**

Figures 10-13 show the construction features of the MK 19 Equipment. The rotor shown in Figure 11 is about 5½ inches in diameter, weighs 8 lb., spins at about 400 revolutions per second, and represents an angular momentum of about $90\times10^6$ gm cm²/sec. The design stresses absolute symmetry of construction, high electrical efficiency, and an efficient lubrication system.

The rotor is sealed within a spherical case. This assembly is accurately balanced under fluid for neutral buoyancy and to bring the centroid of flotation coincident with the center of mass. Many of these units have operated without benefit of maintenance for periods exceeding 12,000 hours of service. An interesting comparison is to consider 12,000 hours of driving your car at 30 mph, thus traveling 360,000 miles, without an oil change or adjustment of any kind! This 12,000 hours (or almost 1½ years) of continuous operation at 400 revolutions per second represents 17 billion revolutions of the rotor with a peripheral travel of the rim of 3½ million miles. One of the early installations on an ice breaker logged over 19,000 hours of satisfactory operation. Two design features contributing to this reliability of operation provide a thermally controlled lubrication system and positive control of the rotor bearing preload.

The sealed gyro unit is then installed in a sensitive gimbal shown in Figure 11. The electrolytic level, angular pickoff and slip rings are then added to this member. This assembly then mounts on the base of the oil filled enclosure as pictured in Figure 12. The Slave Gyro is similar in all construction details.

These completed units are fully adjusted and tested separate from the system, and are stored and installed as interchangeable assemblies.

Figure 13 shows the meridian and slave units installed on the stabilized platform ready for system tests. (Note that the shock mounts are incorporated within the binnacle and a mechanical pantograph linkage serves to provide positive alignment of the stabilization axes.)

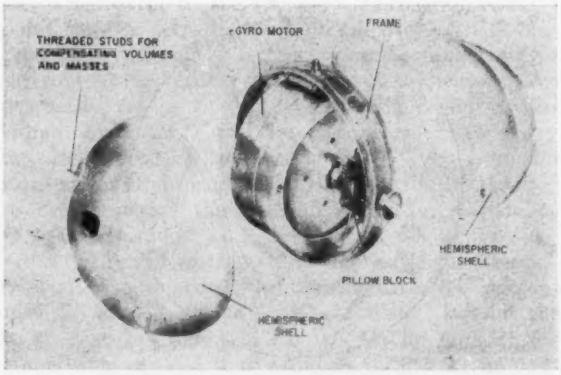



**Figure 10. Gyro motor construction.**

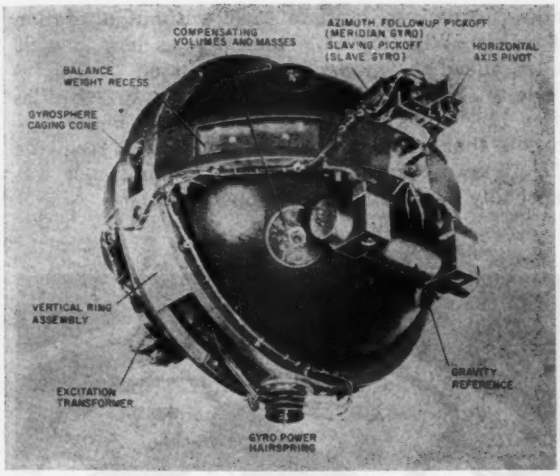



**Figure 11. Gyro gimbal and level assembly.**

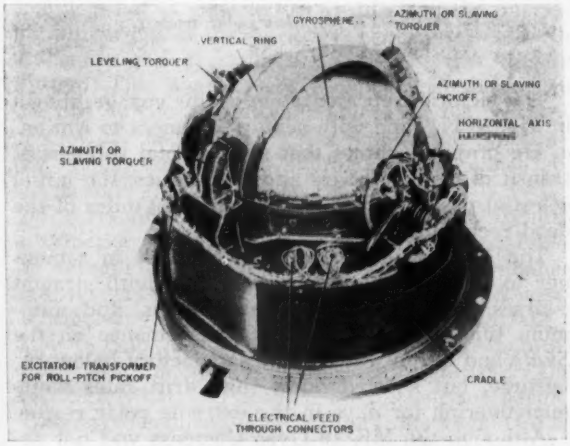



**Figure 12. Meridian gyro mounting.**

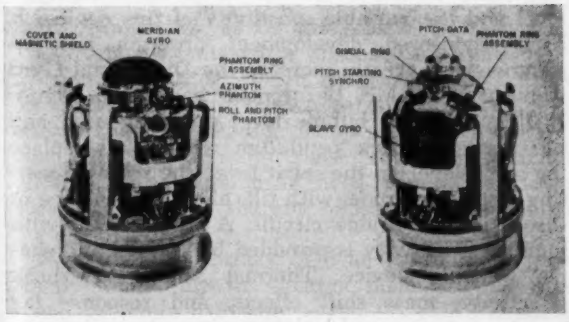



**Figure 13.**

The very slow response characteristics inherent in the gyro control system make it mandatory to avoid any interruption in operation of the equipment. Even a momentary interruption will destroy system accuracies for hours to follow. Provision is made in equipment design to guard against this event. The Control Cabinet of the MK 19 houses the servo amplifiers, power converters, computers, electro-mechanical integrators, indicators, and test circuits. Magnetic amplifiers are used for reliability in the critical stabilizer servos. Electronic amplifiers are applied in parallel to guard against component failure. Monitor and checkout circuits permit failure or replacement of any component without interruption to system operation.

The MK 23 Gyro Compass, represented in Figure 14, incorporates all of the features of the MK 19 meridian gyro, but substitutes a simple pendulous gimbal suspension for the roll and pitch servo stabilized platform. With other design compromises, the equipment represents about one-fourth the complexity, size and cost of the MK 19 Gyro Compass. It, of course, provides only azimuth data. The schematic shows the same control features previously described for the MK 19.

Figure 15 shows the MK 23 Gyro Compass. Its operating reliability is favored by the avoidance of the critical stabilizing servos, by its over-all simplicity, and by its low demand on ship's electrical power. When used as an emergency back-up for MK 19 installations, care should be exercised to see that the MK 23 operates from an independent source of ship's power. Interruptions in the switching of ship's power is the most frequent cause of error in compass operations.

The generally accepted performance accuracies of the MK 19 and MK 23 Gyro Compasses exceed the design specifications by an appreciable amount.

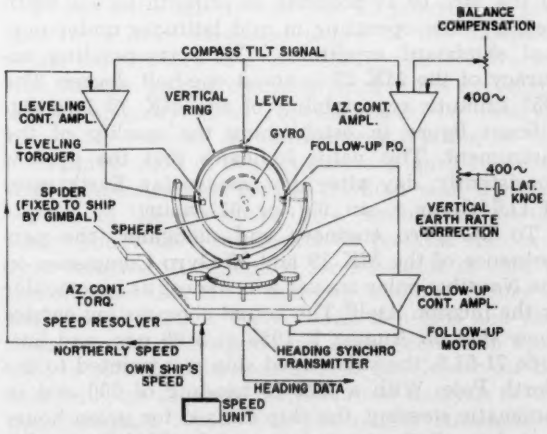



**Figure 14. MK 23 gyro compass and gimbal arrangement.**

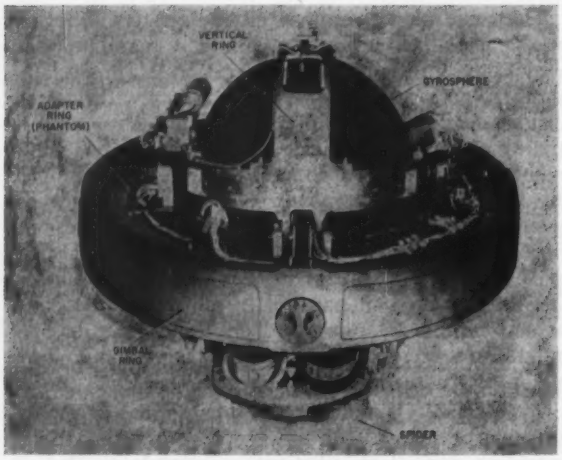
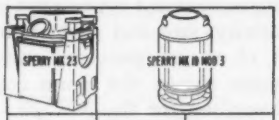



**Figure 15. MK 23 pendulous platform.**




| | AZIMUTH | | AZIMUTH | | ROLL AND PITCH | |
|---|---|---|---|---|---|---|
| FACTORY TEST LIMITING VALUES (DEGREES) | SPEC. | ACTUAL | SPEC. | ACTUAL | SPEC. | ACTUAL |
| SETTLING POINT REPEATABILITY | 0.2 | 0.2 | 0.15 | 0.10 | 0.07 | 0.03 |
| TURNTABLE VARIOUS HEADINGS | 0.7 | 0.3 | 0.15 | 0.10 | 0.07 | 0.03 |
| LOW ANGLE SCORSBY | 1.0 | 0.5 | 0.20 | – | 0.15 | 0.04 |
| HIGH ANGLE SCORSBY | 2.0 | 0.7 | 0.40 | 0.20 | 0.20 | 0.05 |
| SHIPBOARD TEST RMS VALUES (DEGREES) | | | | | | |
| DOCKSIDE REPEATABILITY | – | 0.2 | – | 0.05 | – | 0.02 |
| LIGHT SEA NO MANEUVERS | – | 0.2 | – | 0.05 | – | 0.03 |
| MODERATE SEA NORMAL MANEUVERS | – | 0.5 | – | 0.10 | – | 0.03 |
| HEAVY SEA RADICAL MANEUVERS | – | 1.0 | – | 0.20 | – | 0.05 |

**Figure 16. MK 19 and MK 23 gyro compass performance accuracy (at 40° latitude).**

Figure 16 represents a summary tabulation showing the static and dynamic performance capabilities of these equipments. To generalize, we might classify the MK 19 as accurate in azimuth to one-tenth degree when operating in mid latitudes under normal shipboard conditions. The corresponding accuracy of the MK 23 is about one-half degree. The .05° azimuth repeatability of the MK 19 is a significant figure in establishing the quality of the instrument. This value indicates that the gyro is consistently, day after day, measuring Earth rates of 11.7°/hour × sin .05°, or .01°/hour.

To the gyro engineer and navigator, the performance of the MK 19 and 23 Gyro Compasses on the *Nautilus* polar transit was almost as spectacular as the mission itself! The actual compass log entries show that on August 1, 1958 at 5:00 p.m. and latitude 71-51.8, the submerged ship was pointed to the North Pole. With a MK 19 heading of 000 and in automatic steering, the ship cruised for seven hours that day, all the next day, and for 23½ hours the following day, to latitude 88.46 without alteration of course. With the Pole indicated as less than 90 miles ahead, a small course correction of 3° was made to correct an indicated offset of only 4½ miles after 1100 miles of transit! It is equally impressive to note that the divergence of the MK 23 from the MK 19 never exceeded ±1°. This circumstance was especially reassuring to the operation.

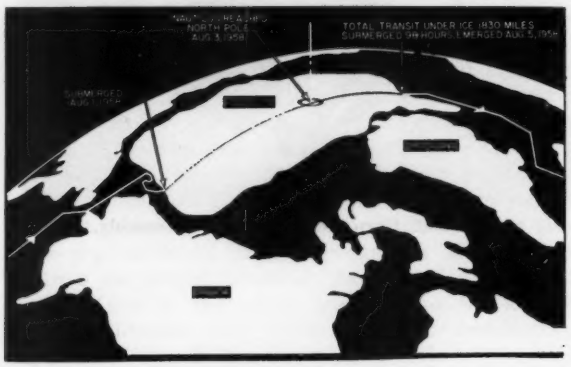



**Figure 17. *Nautilus* polar transit.**

The pictorial representation of this voyage, shown in Figure 17, (and with acknowledgment to *National Geographic*) shows that after a total submerged transit of over 96 hours and 1,800 miles, the initial celestial position fix checked within 10 miles of the dead reckoning position.

The *Nautilus* expedition was planned in a manner to favor gyro compass operation with straight courses, no maneuvering accelerations, and minimum time of transit. MK 19 performance on the *Skate* and *Sargo* was equally satisfactory below 80° latitude, but showed fairly high drift rates while maneuvering for days in the extreme polar region.

Although the MK 19 Gyro Compass was not designed to be operated as a Directional Gyro for grid-type navigation in the polar region, the equipments on the *Nautilus, Skate* and *Sargo* have been modified for such use. The present design is not ideally suited to this type operation because of the mass shift effects of the bubble in the electrolytic level and the variable sensitivity of this device. A Navy sponsored development program now in progress will greatly increase the Directional Gyro stability of the MK 19 for polar navigation. Figure 18 illustrates the bubble level presently used and the force feedback pendulum which will replace the spirit level. In the spirit level, the variable wetting of the electrode, with tilt, alters the balance of the resistance bridge circuit. A clean signal with high tilt sensitivity is provided by a small and simple, reliable device. Thermal sensitivity, shock sensitivity, mass shift effects, and response lag are, however, considered to limit system perform-

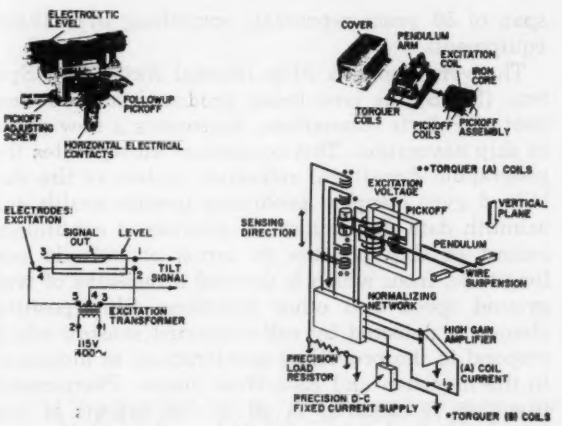



**Figure 18. Liquid level versus torque feedback accelerometer.**

ance accuracies, particularly in the Directional Gyro mode of operation.

The force feedback pendulum is somewhat more complex, but is expected to avoid all of the operating limitations of the spirit level and improves both the static and dynamic accuracies of the MK 19 System. This modification is equally applicable to the MK 23 System. Other features in this redesign of the MK 19 Gyro Compass will further simplify the system and lead to improved performance accuracies.

The requirement for precise zenith and azimuth information, with absolute accuracy and stability for satisfying the increasing demands of ordnance and navigation, represents a continuing need within the Navy for the gyro compass. In this talk I want to help you to fully understand those features that make the gyro compass ideally suited to the normal navigational needs of the nuclear submarine.

The gyro compass is automatic in its alignment to the meridian plane through the Earth's polar axis. It requires only to feel the force of gravity and to sense the daily rotation of the Earth about its polar axis. These two natural quantities persist in all parts of the Earth and for all time. They exist inside the vessel as well as outside, and penetrate the depths of the ocean. They are unaffected by daylight or nightfall, or by the seasons of the year. They cannot be altered or obscured by weather or by man-made interference. The gyro compass thus provides our ships with secure, continuous and precise compass information independent of the stars, magnetic fields or radio transmission. For compass information, a submarine need never break the ocean surface and thereby expose its presence to the enemy.

Navigational accuracy of dead reckoning is primarily limited by the lack of means to measure speed precisely over the bottom. A ship's heading error of 0.1° represents an offset from course of less than 2 miles in position after 1000 miles of transit. If we could measure ground-speed precisely, this 2 miles would be our position error. Today with uncharted ocean currents and limitations in measuring speed through the water, an uncertainty of 1 knot in estimating bottom speed can develop position errors up to 30 miles or more in a 1000-mile mission. Some day we will find a secure means to measure ground speed.

The MK 19 made available for the first time in a submarine a precise zenith reference. A logical and relatively simple outgrowth of this program was to bring this information into the periscope so that star altitude measurements could be made for a celestial position fix. This equipment constitutes a periscopic sextant known as the *S*ubmarine *C*elestial *A*ltitude *R*ecorder (SCAR), shown in Figure 19. This equipment is installed on a number of our advanced submarines and for the first time permits the vessel to establish its position by celestial reference without surfacing.

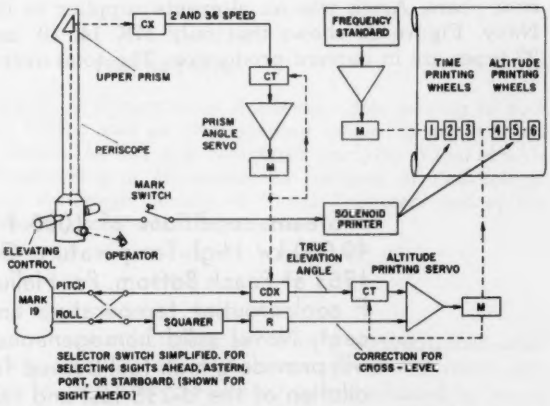



**Figure 19. Block diagram of present SCAR.**

To place the MK 19 and MK 23 program in perspective I have tabulated a few of the mileposts in the long history of gyro instrumentation. We are told that the unique characteristics of the gyroscope were first analyzed by Newton, based on observations and theories of astronomers relating to the cyclic precession of the equinoxes. Figure 20 shows that Bohenberger in 1827 is credited with the conception of the gyroscope as a mechanical device. Lang, about 1846, suggested its possible use as a gyro compass. It remained for Foucault in 1852 to demonstrate this effect and expound the theory of the device. Trouvè, Kelvin, van den Bos and Siemens contributed significant experimentation from 1865 to 1885. Martienssen in 1905 developed, for the first time, an accurate mathematical analysis of the gyro compass. About five years later Anschutz in Germany and Elmer Sperry in New York produced

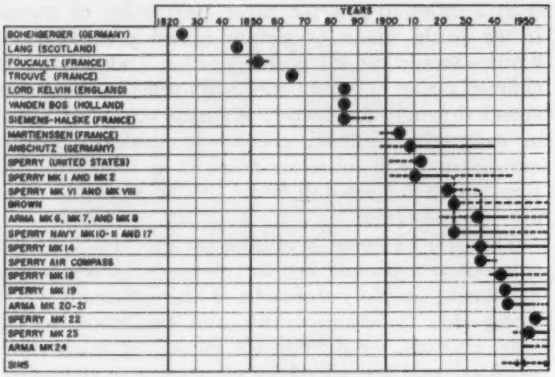



**Figure 20. Chronology of gyro navigation.**

the first practical shipboard equipments.

Following the first Navy gyro compass installation in March, 1913 the Navy has continued to purchase various types of navigational and ordnance gyro compasses. From the early twenties until recent years, Arma was an alternate supplier to the Navy. Figure 20 shows that only MK 14, 19, and 22 types are in current production. The total over a span of 50 years represents something over 10,000 equipments.

The very complex *S*hip *I*nertial *N*avigation *Sys*tem (SINS), as now being produced for our new fleet of Polaris submarines, represents a new phase in ship navigation. This equipment incorporates the geographic directional reference system of the stabilized gyro compass producing precise zenith and azimuth data. In addition, it provides a continuous record of ship position in terms of latitude and longitude, from which is derived a measure of true ground speed and other functions. Ship position change is detected by self-contained sensors which respond to the prevailing accelerations as measured in the meridian and East-West planes. Phenomenal precision is required in all of the outputs of this instrument to satisfy the specialized ordnance use for which it serves in directing the Polaris intermediate range missile. In its present concept, the GYRO NAVIGATOR as used in SINS is necessarily monitored by an array of support equipment and requires continuous supervision which can only be justified for the most vital missions. Most of our Navy will continue to depend on the gyro compass to meet its normal navigation, surveillance, and ordnance needs.

Steam conditions of 1000 F and 1450 psi will be attained on the 40,000-kw High-Temperature Gas-Cooled Reactor to be completed in 1963 at Peach Bottom, Pa. Helium gas cooling will make possible a 1380-F coolantoutlet temperature and a thermal efficiency of about 40 per cent. Novel solid homogeneous graphite-clad fuel-moderator elements will provide a high fuel burnup for each core loading because of the high dilution of the U-235 fuel and fertile thorium 232 by the graphite moderator, and because of the small ratio of parasitic absorbers involved in the reactor's core structure. Core lifetime will be about three years.

The details were given in a paper, "The Application of High-Temperature Gas Cooling to Nuclear Power Plants" presented by Frederic de Hoffmann, senior vice-president of General Dynamics Corporation and president of the General Atomic Division. Dr. de Hoffmann presented the paper at the conference on small and medium-power reactors sponsored by the International Atomic Energy Agency, at Vienna, Austria.

The HTGR is being built by Philadelphia Electric Company, together with 52 other U.S. utility companies which make up High Temperature Reactor Development Associates, Inc. The 53 utilities represent the largest group of companies ever to support a nuclear power project in the United States.

—From MECHANICAL ENGINEERING
November 1960

LT ROBERT S. LUCAS, USCG

# SOME ENGINEERING PROBLEMS INVOLVED IN THE DESIGN OF HYDROFOIL SUPPORTED CRAFT

THE AUTHOR

*is a 1952 graduate of the U. S. Coast Guard Academy. After serving in both Deck and Engineering billets, and as Commanding officer of an overseas LORAN transmitting station, he has just completed studying Naval Architecture and Marine Engineering at Massachusetts Institute of Technology. He is a member of the American Society of Naval Engineers and of the Society of Naval Architects and Marine Engineers.*

SUMMARY

AS THE TITLE SUGGESTS, the subject matter of this paper is limited to but a few of the many problems associated with the design and operation of hydrofoil supported craft. Hull design and foil configuration are two of the many problems which are not the concern of this paper, although both are mentioned.

The major design considerations which are discussed are (a) Power Plants, (b) Transmission and Shafting and (c) Propellers. The solutions to these problems which have been devised to date are included.

## INTRODUCTION

The term hydrofoil is commonly used to describe a craft whose hull is supported clear of the water surface while underway by the dynamic lift of submerged hydrofoils or underwater wings. Hence their use makes possible the adoption of simplified hull form and light construction. For certain speed-length ratios, a hydrofoil offers a substantial reduction in resistance and an improvement in seakeeping ability. Consequently, greater speed may be attained than that possible with a conventional craft with equal power, or the same speed with much less power, and this speed may be maintained in much rougher seas.

The advantages of hydrofoils are restricted to craft of fairly small tonnage; Reference [1] shows that the maximum practical size of such craft is limited to about 1500 to 3500 tons. This maximum size cannot be increased until some new developments in power plants result in greatly reduced specific weights. Other difficulties which limit size at this time are (1) limitations on maximum torque that can be absorbed in present-day transmissions of the right-angled or V-types, (2) the large foil size compared to hull size as the size of craft is increased and (3) the fact that size and/or number of struts must increase with size out of proportion to other dimensions. Also, special cargo handling, docking, and launching facilities would be required for large hydrofoil ships, since retraction of the foils becomes very undesirable with large size.

Admitting the limitations as to size, there remains the fact that many applications are possible for small, high-speed craft. These include (1) comfortable point-to-point passenger service, (2) pleasure

craft, (3) crash-boat or air-sea rescue boats, (4) landing craft and (5) other military applications for stable small craft which can travel in comparatively rough seas at high speed.

### POWER PLANTS

The over-all design of hydrofoil boats is materially affected by the characteristics of available power plants. As in any boat or ship in the higher speed ranges, lower machinery weight and lower fuel consumption give a better design. In small sizes, the hydrofoil can compete with other craft on an equal machinery basis. In larger sizes, the great growth of foil size with increased weight places an added penalty on heavy machinery. Large hydrofoil craft cannot be considered practical until very light high-powered machinery is developed. For instance, for an 8000-ton, 500-foot, 50 knot hydrofoil ship to be possible requires a large capacity power plant (approximately 300,000 HP) with a specific weight in the order of 25 percent of that of present units. [1]

The successful hydrofoils to date have used either high speed diesels or gasoline engines. However, the gas turbine power plant is very desirable for such application, because of the low specific weights of these units. The gas turbine is also smaller in size than a comparable diesel or gasoline engine, and fuel consumption, while somewhat higher than diesel engines as a rule, is not a major problem.

The application of nuclear power to large hydrofoils will not be possible as long as the specific weight of the plant is so large, although such an application is being investigated for the Maritime Administration.

The simplicity of air screw propulsion is most attractive for high speeds, and must be evaluated on an efficiency and weight basis against marine propulsion. To achieve reasonable efficiency of air propulsion either very large propellers or speeds of advance that are very high in terms of marine practice are required. For speeds over 50 knots, air propulsion becomes desirable and would certainly present fewer problems than marine propulsion at such speeds. The summary of hydrofoils at the end of this paper includes an outstanding example of an air-propulsion hydrofoil.

### TRANSMISSION AND SHAFTING

The transmission and shafting problems of hydrofoils are much greater than those encountered in conventional craft, and present a large obstacle to be overcome. The power must be transmitted from the prime mover in the hull down to a propeller at about the deepest level of foil submergence, a distance of several feet even in a small boat. In addition, the propulsion supports, gearing, bearings, and associated equipment cannot present a bulky mass under the water or large drag penalties are incurred.

The solutions to this problem have consisted of two different ideas. In the first and most successful to date, the prime mover is inclined forward and drives into a V-gear, so that the shaft is inclined aft from a point well forward in the boat. This results in a fairly large shaft angle, but puts the propeller into a region of very excellent flow conditions; this results in a high value of propulsive coefficient. The second solution is the use of double-right-angled gearing. This has not been as successful as the first solution, because of (1) gear failures, (2) greater weight, (3) air entrainment of the rear strut and (4) increased hydrodynamic drag. This is the newer solution, and the one most favored in the United States, while the first has been successfully used by Italy, Germany, Russia, The Netherlands, and Switzerland. This method does put the propeller shaft horizontal or nearly so, but the flow conditions are not as good as in the first case because of the strut which is necessarily just ahead of the propeller. Air entrainment of the rear strut has two effects; a lateral force or lift is produced on the wetted side of the strut, and propeller thrust is completely lost causing a landing. Temporary air entrainment may cause a veering-off from course or very poor directional stability. [2]

An additional transmission problem arises with the use of gas turbine propulsion. [4] Gas turbines are not reversible, and hence would require either (1) some sort of mechanical geared drive containing reversing features, (2) mechanical geared drive with a controllable-pitch propeller or (3) an auxiliary diesel engine for manuevering purposes. The third solution is probably the most simple, although the first would probably result in least weight. The controllable-pitch propeller solution presents many difficulties because of the gearing and because of the small size propellers, but would seem to be the best solution for larger size hydrofoils.

### PROPELLERS

Propeller cavitation becomes a problem to contend with at high speeds, and is practically impossible to avoid. Even the successful hydrofoils to date have operated with ordinary propellers and varying amounts of cavitation. Such cavitation greatly hinders performance by reducing thrust, torque, and efficiency.

The problem of selecting a propeller for a hydrofoil vessel differs from the usual considerations in that the propeller must fulfill conflicting requirements. It must provide sufficient thrust for takeoff as well as for the full speed performance. The takeoff condition is the most critical for without takeoff, the full speed condition will never be reached. [2] The normal procedure is to select the most efficient propeller for a designed speed, horsepower, and RPM. With a hydrofoil, this most efficient top speed propeller may not have sufficient thrust at takeoff speed to get the boat over the drag hump and onto the foils.

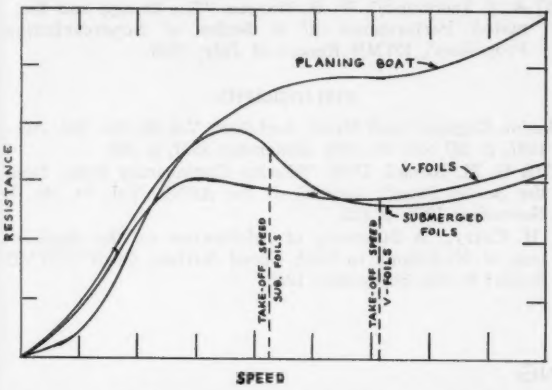



**Figure 1. Typical speed-drag curves for a planing boat and for two hydrofoil boats. The "drag hump" is emphasized in the case of the submerged-foils craft.**

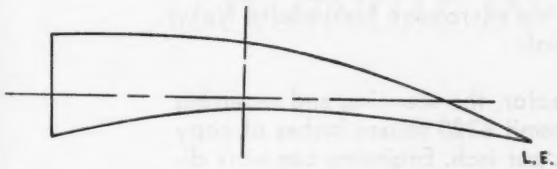



**Figure 2. Typical supercavitating-propeller blade section.**

If an attempt is made to select a propeller that will absorb full power at full speed, but have its maximum efficiency at a lower speed, i.e. the propeller with maximum thrust and maximum range of thrust, the solution becomes a whole series of solutions for each set of conditions considered as the takeoff point (speed, HP, and RPM). The difficulty is increased by the fact that probably both face and back cavitation exists on the propeller. [2]

A new approach has been made to this problem. Since suppression of cavitation becomes impossible at the higher speeds, it is necessary to investigate propellers which are designed to operate at low cavitation numbers. Operation in this speed range results in the back side of the blade being completely enclosed within a vapor cavity which originates at the leading edge of the blade and extends beyond the trailing edge. Propellers exhibiting this type of flow configuration are known as SC or supercavitating propellers.

A procedure has been developed for the design of SC propellers at the David Taylor Model Basin. [3] In order to have satisfactory supercavitating operation, the cavitation number $\sigma_x = \frac{p - p_0}{\frac{1}{2}\rho V^2}$ should be less than 0.045, which requires a high rotational speed at speeds of advance between 35 and 50 knots. This high rotational speed results in a low pitch and low propeller efficiency. As the speed of advance is increased, a considerable gain in efficiency results. One successful SC propeller rotates at 3000 RPM at 50 knots, with a thrust of 3500 pounds; another smaller propeller designed for 680 pounds of thrust at 65 knots rotated at 7040 RPM. [3] The efficiency of these propellers drops off rather rapidly at speeds of advance below the design point, which may present a problem for hydrofoil boats near the drag hump speed.

For SC-propeller use at lower speeds of advance, the cavitation number may be decreased artificially by increasing the cavity pressure. This is done by providing an air passage from the back of the blade through which air can be sucked or injected. Such propellers are known as ventilated or force-ventilated propellers.

The design of an SC propeller for a given set of design parameters leads to a rather complex investigation and usually results as a compromise between the hydrodynamic considerations, the acceptable stress limit, and the practical limitations on propeller diameter. SC propellers are subject to leading edge vibration and fatigue failure, since the sections are inherently thin at the leading edge. For these reasons it is necessary to use high-strength material and a large factor of safety. [5]

There is very little operating experience with SC propellers, but those that have been used have proven satisfactory. One propeller that was designed according to the method given in Reference [3] was tested with good results on the Canadian R-100 research hydrofoil, and gave good results close to those predicted by the design method.

## Appendix I

*Summary of Hydrofoil Boats and Comparison with Conventional Craft*

### A. HYDROFOILS

| Name | Type | Year | Disp. Tons | Instal. HP | Max. Speed | Remarks |
|---|---|---|---|---|---|---|
| HD-4 | Research | 1918 | 5.5 | 700 | 60 | Air propulsion; USA |
| *Bremen* | Passenger (60) | 1953 | 22 | 1300 | 38 | In service; gasoline; Germany |
| *Messina* | Passenger (72) | 1954 | 26 | 1350 | 40 | In service; diesel; Italy |
| *Aquastrol* | Passenger (27) | 1957 | 13 | 600 | 38 | In service; diesels; Dutch |
| *Raketa* | Passenger (66) | 1957 | 23 | 900 | 39 | In service; diesel; Russia |
| R-100 | Research | 1957 | 8.5 | 450 | 50 | Canada |
| *Halobates* | Research | 1958 | 13.8 | 650 | 34 | Landing craft; gas turbine being fitted |

### B. DISPLACEMENT AND PLANING CRAFT

| Name | Type | Year | Disp. Tons | Instal. HP | Max. Speed |
|---|---|---|---|---|---|
| Huckins | PT | 1941 | 58 | 7500 | 36 |
| Higgins | PT | 1941 | 55 | 7500 | 35 |
| MK 1 | Rescue, 45′ | 1945 | 14.3 | 1260 | 33 |
| MK 1A | Rescue, 40′ | 1945 | 11.6 | 330 | 20 |
| Coast Guard | Utility, 40′ | 1955 | 9.6 | 330 | 22 |
| Crash boat, | 63′ | 1946 | 28 | 1260 | 28 |

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[3] A. J. Tachmindji, W. B. Morgan, W. L. Miller, and R. Hecker, "The Design and Performance of Supercavitating Propellers", DTMB Report C-807, February 1957.

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[5] A. J. Tachmindji, W. B. Morgan, "The Design and Estimated Performance of a Series of Supercavitating Propellers", DTMB Report of July, 1958.

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## RECORDING

A high-speed electronic "document retriever," billed as the world's fastest, has been unveiled by the Navy's Bureau of Ships. It was developed by the Hogan Faximile Division of Telautograph Corporation over a 3-year period at a cost of some $270,000. Design and engineering data for ship construction will be transmitted via microwave facsimile to Navy shipyards as the first use of the equipment.

Combined with a microfilm rapid selector, the scanning and receiving units of the document retriever can transmit 4320 square inches of copy per minute with a resolution of 100 lines per inch. Engineers can work directly from transmitted facsimile.

Navy plans to evaluate the retrieval equipment for around six months. Ultimately it wants to link all 11 Navy shipyards with the Bureau of Ships headquarters in Washington. Design and engineering data will then be flashed to the shipyards. Even instruction manuals and other such material are planned to be distributed via the new system.

Advantages of the document retriever are more speed and less cost. Blueprints can be transmitted by the Bureau of Ships to the yards in a matter of minutes. And the cost of the tons of blueprints necessary for the Navy's ship-construction program can be reduced from the 5 cents-per-square-foot average now to only about 1.6 cents per square foot with the facsimile system.

Production costs of the document retriever are expected to run around $70,000, with the receiving equipment accounting for some $55,000 of this cost. Both the military and industry are looking at the new document retriever to explore additional uses for it. (PRODUCT ENGINEERING, November 28, 1960, Page 13)

"MARINE NEWS"

# *ALUMINUM IN MARINE ENVIROMENTS*

**ACKNOWLEDGMENT**

*This article was written by R. I. Lindberg, corrosion engineer with Reynolds Metals Company. It appeared in the September 1960 "Marine News" from which it is reprinted.*

THE INCREASING use of aluminum in marine applications is based on an experience of some 65 years. In 1895 [1] a number of small boats were put in service, including torpedo boats for the French and Russian Navies. With the passage of time improved alloys of the aluminum-magnesium and the aluminum-magnesium-silicon types have superseded the nearly pure aluminum alloys that were used in the early vessels. At the present time, alloys of the 5XXX and 6XXX series are widely used in marine construction.

Marine exposures consist of three environmental conditions:

1) Continuously submerged.

2) Alternately submerged.

3) Exposed to the atmosphere near or over water. In the latter case, actual wetting occurs only as a result of rain, condensation or by spray or splash. The mechanisms of corrosion are the same in either fresh or salt water, but salt water is more severe. The increased corrosivity of salt water results from its better electrical conductivity and from the attack of the aggresive chlorine ion which it contains.

When materials are tested for resistance to marine corrosion, they are usually exposed to conditions where they are:

1) Wetted continuously by being submerged.

2) Wetted regularly by alternate immersion, i.e., tidal zone.

3) Near but not in the water, i.e., on racks on a beach or wharf.

All three conditions are necessary to properly evaluate a material.

The type exposure is less important for aluminum than for steel as the data in this report will show, but the data for steel illustrate the effect of location. The sensitivity of steel to exposure location was first described by F. L. LaQue [2] in 1951. LaQue's data showed corrosion rates of 4 to 5 mils per year (mpy) at areas below average low tide. At areas 1 to 2 feet above average high tide, the rate increased to 25 mpy for small individual specimens. When a long continuous specimen was exposed, the maximum rate was about 15 mpy.

## CORROSION BY MARINE ATMOSPHERES

A great deal of testing on the resistance of materials to marine atmospheres has been done at test

TABLE 1

*Effect of Marine Atmospheres on the Mechanical Properties of Aluminum Alloys. Data from Proceedings of ASTM, 1953-1955*

| Alloy | Time (mo.) | Control Y.S. | Control T.S. | Control El. | Kure Beach Y.S. | Kure Beach T.S. | Kure Beach El. | Point Reyes Y.S. | Point Reyes T.S. | Point Reyes El. | Freeport Y.S. | Freeport T.S. | Freeport El. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5052-H34 | 6 | 28,000 | 34,900 | 10.0 | 28,700 | 35,700 | 9.6 | | | | | | |
| .064" Sheet | 12 | " | " | " | 28,300 | 34,800 | 10.0 | | | | | | |
| | 36 | 27,900 | 35,600 | 10.6 | 28,000 | 35,000 | 10.2 | 28,000 | 34,800 | 10.8 | 26,900 | 33,000* | 9.8 |
| 5050-H34 | 6 | 24,500 | 27,400 | 8.0 | 24,500 | 27,700 | 7.6 | | | | | | |
| .064" Sheet | 12 | " | " | " | 23,800 | 27,200 | 7.5 | | | | | | |
| | 36 | 23,600 | 27,900 | 8.5 | 24,200 | 27,600 | 8.4 | 24,300 | 27,600 | 7.8 | 23,200 | 26,700 | 6.0 |
| 6061-T6 | 6 | 43,300 | 47,300 | 11.0 | 42,900 | 46,700 | 12.1 | | | | | | |
| .064" Sheet | 12 | " | " | " | 41,400 | 46,700 | 12.3 | | | | | | |
| | 36 | 42,900 | 47,500 | 10.2 | 42,200 | 47,200 | 12.0 | 39,500 | 45,400 | 11.0 | 42,000 | 45,500 | 10.0 |
| 6061-T6 | 6 | 40,500 | 46,100 | 16.5 | 39,900 | 46,000 | 18.0 | | | | | | |
| .25" Plate | 12 | " | " | " | 40,300 | 45,800 | 17.0 | | | | | | |
| | 36 | 42,800 | 47,000 | 16.9 | 41,300 | 46,800 | 16.1 | 43,000 | 46,800 | 15.5 | 41,200 | 46,000 | 15.5 |
| 6061-T6 | 6 | 40,300 | 43,500 | 15.0 | 39,600 | 42,700 | 17.0 | | | | | | |
| .25" Bar | 12 | " | " | " | 39,800 | 42,900 | 15.5 | | | | | | |
| Extruded | 36 | 41,200 | 43,900 | 16.6 | 40,500 | 43,100 | 15.8 | 41,400 | 43,500 | 14.8 | 40,900 | 43,200 | 14.0 |
| 6063-T5 | 6 | 23,700 | 28,600 | 16.0 | 23,900 | 28,000 | 16.5 | | | | | | |
| .25" Bar | 12 | " | " | " | 27,100 | 31,000 | 15.5 | | | | | | |
| Extruded | 36 | 24,600 | 29,000 | 17.0 | 24,900 | 29,800 | 15.2 | 26,400 | 29,800 | 14.6 | 25,000 | 29,000 | 15.8 |

Y.S.—Yield Strength, psi, 0.2% offset. T.S.—Ultimate Tensile Strength, psi. El.—% Elongation in 2". *Low.

TABLE 2

*Depth of Attack of Aluminum Alloy Assemblies Partially Immersed in Flowing Sea Water at Kure Beach Data from C. J. Walton and E. T. Englehart* [4]

| Plate Alloy | Method of Joining | Exposure Period | Average Depth—mils (0.001") Plate: Outside Surface | Average Depth—mils (0.001") Plate: Faying Surface | Average Depth—mils (0.001") Plate: Rivet or Weld | Maximum Depth—mils (0.001") Plate: Outside Surface | Maximum Depth—mils (0.001") Plate: Faying Surface | Maximum Depth—mils (0.001") Plate: Rivet or Weld |
|---|---|---|---|---|---|---|---|---|
| | | | Total Immersion in Sea Water | | | | | |
| 5053-T6 | riveted—53S-T6 | 6 yr. | 0.7 | 0.5 | 1.5 | 1.4 | 3.0 | 8.4 |
| 6061-T6 | riveted—61S-T43 | 1 yr. | 0.7 | 1.4 | 0.7 | 1.4 | 2.8 | 2.8 |
| 5053-T6 | welded—43 alloy | 2 yr. | 1.2 | .. | 2.1 | 5.0 | .. | 4.2 |
| 6061-T6 | welded—43 alloy | 1 yr. | 1.8 | .. | 2.4 | 5.0 | .. | 9.8 |
| 6061-T4 | Panel | 3 yr. | 0.9 | .. | .. | 2.1 | .. | .. |
| 6061-T6 | Panel | 3 yr. | 0.5 | .. | .. | 1.4 | .. | .. |
| | | | Atmosphere | | | | | |
| 5053-T6 | riveted—53S-T6 | 6 yr. | 2.8 | 1.6 | 4.3 | 5.6 | 5.6 | 11.7 |
| 6061-T6 | riveted—61S-T43 | 1 yr. | 2.8 | 0.7 | 4.2 | 5.6 | 2.1 | 8.5 |
| 5053-T6 | welded—43 alloy | 2 yr. | 1.7 | .. | 2.1 | 3.3 | .. | 9.8 |
| 6061-T6 | welded—43 alloy | 1 yr. | 1.4 | .. | 2.8 | 7.0 | .. | 9.8 |
| 6061-T4 | Panel | 3 yr. | 1.1 | .. | .. | 2.1 | .. | .. |
| 6061-T6 | Panel | 3 yr. | 1.4 | .. | .. | 4.2 | .. | .. |

sites all over the world. The following data are representative and have been obtained from the literature.

Table 1 is a summary of pertinent data presented by the ASTM [3] which shows the effect of various marine environments on the physical properties of aluminum alloys.

In 1949 Walton and Englehart [4] presented data on both pitting attack and loss of properties for aluminum exposed in many places. Table 2 reproduces their data for the marine alloys.

Walton and King presented data for the ASTM [5] which showed depth of attack for various alloys. These data, contained in Table 3, are interesting since they illustrate the excellent resistance to corrosion of a range of aluminum alloys.

Samples of several alloys were exposed for Reynolds Metals Company at the facilities of the Lago Oil and Transport Company on the Island of Aruba in Netherland Antilles. Exposure was for one year under atmospheric, tidal and total submersion conditions. Specimens were supported on piers in the Caribbean Sea.

TABLE 3

*Corrosion of Aluminum Alloys Exposed about 20 Years to Sea Atmosphere. Evaluated by Calculated and Measured Depths of Attack*

| Location | Type of Atmosphere | Exposure Time, Year | 1100-H14 | 3003-H14 | 6051-T4 |
|---|---|---|---|---|---|
| **Average Penetration Calculated from Loss in Weight, Mils** | | | | | |
| Key West | Seacoast | 19.67 | ... | ... | 0.06 |
| Sandy Hook | Seacoast | 20.37 | 0.22 | 0.28 | 0.27 |
| La Jolla | Seacoast | 18.15 | 0.46 | 0.48 | 0.61 |
| **Average Measured Depths of Attack, Mils** | | | | | |
| Key West | Seacoast | 19.67 | 1.7 | 1.0 | 2.5 |
| Sandy Hook | Seacoast | 20.37 | 3.8 | 1.4 | 2.3 |
| La Jolla | Seacoast | 18.15 | 4.0 | 4.2 | 3.3 |
| **Maximum Measured Depths of Attack, Mils** | | | | | |
| Key West | Seacoast | 19.67 | 4.9 | 4.6 | 6.7 |
| Sandy Hook | Seacoast | 20.37 | 9.1 | 3.3 | 5.4 |
| La Jolla | Seacoast | 18.15 | 14.0 | 10.2 | 12.1 |

The atmospheric specimens experienced pitting attack which did not exceed one mil (.001"). Depth of attack was so slight that visual appearance was used to rate the alloys. This rating, in descending order of appearance, was as follows:

| Marine Atmosphere | Marine-Industrial Atmosphere |
|---|---|
| 5052-H32; 5083-O | 5083-O |
| 6063-T5; 6063-T6 | 6063-T6 |
| 6061-T6 | 6063-T5 |
| 3003-H14 | 6063-T4 |
| Alclad 3004-O | 5052-H34 |
| Alclad 6061-T6 | 3003-H14 |
| | Alclad 6061-T6 |
| | Alclad 3004-O |

### SUMMARY OF MARINE ATMOSPHERIC EXPOSURE DATA

Aluminum corrodes by pitting in marine atmospheres but the extent of this pitting is so slight that in tests of three years' duration no appreciable loss in strength occurred. Depth of pitting will vary considerably from place to place but will generally not exceed four or five mils total depth in twenty years. The maximum depth of attack may reach as much as fourteen mils in twenty years under adverse conditions.

### EXAMPLES OF ALUMINUM USED IN MARINE ATMOSPHERES

The use of aluminum in ship superstructures is expanding rapidly. Over 2,000 tons were used on the *United States* and each of the new English liners, *Canberra* and *Oriana* used over 1,000 tons of aluminum. Many other large ships have utilized substantial quantities of aluminum not only for deckhouses, but for life boats, ladders, tank covers, gangways and awnings.

Naval uses are diverse and substantial—over two million pounds of aluminum are used in a *Forrestal* Class carrier, and destroyers and frigates use 200,000 to 300,000 pounds each.

In architectural applications, aluminum is preferred for applications such as curtain walls and roofs. Godard [6] reports on the excellent performance of aluminum buildings erected in 1949-50 on the tropical island of Kaasa in French Guina. In this application, homes, warehouses and dock structures were sheathed in aluminum. Godard also reports the results of ten-year ASTM tests on the comparative atmospheric corrosion rates of several metals. Those parts of his data referring to marine exposure are reproduced as Table 4.

TABLE 4

*A.S.T.M. Ten-Year Atmospheric Corrosion Rates Corrosion Rates in m.p.y.**

| Location | Atmosphere | Al. | Cu. | Pb. | Zn. |
|---|---|---|---|---|---|
| Key West, Fla. | Marine | 0.004 | 0.020 | 0.022 | 0.021 |
| Sandy Hook, N. J. | Marine | 0.008 | 0.026 | ... | 0.055 |
| La Jolla, Calif. | Marine | 0.028 | 0.052 | 0.016 | 0.068 |

* m.p.y.—mils per year—calculated from weight loss. Data from C. J. Walton and E. T. Englehart [4].

Walton, Sprowls and Nock reported the results of extensive weathering tests in 1953. Their conclusions are here quoted in their entirety.

"1. Outdoor exposure of thousands of specimens for long periods to a variety of conditions, including severe industrial and seacoast atmospheres, shows that aluminum alloy products, both wrought and cast, have a high resistance to atmospheric weathering.

"2. This is attributable to the 'self-stopping' nature of the attack of aluminum alloys; that is, the formation of protective films which causes the rate of weathering to decrease markedly with time.

"3. The data indicate that after an initial exposure period of about one or two years, the maximum rate of penetration of corrosion is expected to be appreciably less than 0.2 mil per year for the more adverse conditions, such as severe seacoast atmospheres and less than 0.1 mil per year for atmospheric weathering conditions normally encountered.

"4. Although some differences in resistance to weather were noted among the aluminum alloys, the differences often were of little practical significance so that final choice of alloy would be based on other important requirements, such as strength, formability, weldability, appearance and cost.

"5. Alclad products are characterized by a high resistance to weathering and also by a unique resistance to perforation. The performance of alclad alloys makes them especially valuable for applications involving relatively thin sheet products for use under adverse conditions."

### UNDERWATER AND TIDAL EXPOSURE OF ALUMINUM

Table 2, previously presented, contains sections on totally immersed aluminum samples. Table 5 contains data showing the change in strength of

TABLE 5

*Results of Exposures in Sea and Harbor Waters. Per Cent Change in Tensile Strength* [1]

| Alloy | Period in Yr. | Montreal, Que. | | Black Rock Harbor, Conn. | | East River, New York | | Norfolk, Va. | | Miami Fla. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. |
| 5052-H34 | 1 | + 1 | — 4 | — 1 | — 2 | — 5 | — 2 | — 2 | — | 0 | 0 |
| 5052-H34 | 2 | — | — | — | — | — | — | — | — 4 | — 2[2] | —1[2] |
| 5053-T6 | 1 | — 3 | — 4 | — 8 | — 4 | —39 | — 6 | + 4 | — | — | — |
| 5053-T6 | 2 | — | — | — | — | — | — | — | —11 | — | — |
| 6061-T6 | 1 | — | — | —11 | — 1 | — | — | — | — | — 9[2] | — |
| 6061-T6 | 2 | — | — | — | — | — | — | — | — | — | — |
| Steel | 1 | —20 | — 8 | —26 | —40 | — | — | —49 | — | — | — |
| Steel | 2 | — | — | — | — | —32 | —61 | — | —52 | — | — |

| Alloy | Period in Yr. | Mobile, Ala. | | New Orleans, La. | | Hudson River, Edgewater, N.J. | | Freeport, Texas | | Corpus Christi, Texas | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. | C. I. | A. I. |
| 5052-H34 | 1 | — | — | — | — | — | — | — 4[4] | — | — | — |
| 5052-H34 | 2 | — 4 | — 3 | — 2 | — 1 | — | — | — | — | —13 | — |
| 5053-T6 | 1 | — | — | — | — | — 4 | + 2 | — | — | — | — |
| 5053-T6 | 2 | — 2 | — 1 | — 1 | — 1 | — | — | — | — | — | — |
| 6061-T6 | 1 | — | — | — | — | — | — | — 5[4] | — | — | — |
| 6061-T6 | 2 | — | — | — | — | — | — | — | — | —12 | — |
| Steel | 1 | — | — | — | — | —13 | —52 | —22[4] | — | — | — |
| Steel | 2 | —35 | —16 | — 9 | —11 | — | — | — | — | —100 | — |

[1] These results are based on averages from three tensile specimens 0.064-inch thick cut from panels after exposure. In many cases, they are averages from panels from several lots of material.
[2] Exposed four years. [3] Exposed three months. [4] Exposed seven months.
[5] C. I. means continuously immersed, and A. I. means alternately immersed.

aluminum alloys exposed in many marine areas in both continuously and alternately immersed conditions. These data are also from Walton and Englehart [4].

Data from a Canadian investigation [8] to determine *maximum* pit depth of aluminum alloys immersed in sea water at Halifax, Nova Scotia; Esquimalt, British Columbia; and Harbor Island, North Carolina are given in Table 6.

TABLE 6

*Pitting of Aluminum Alloys in Sea Water. Maximum Pit Depth in Mils. Data from H. P. Godard*

| Alloy | Year | Halifax | | | Esquimalt | | | Harbor Island | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 5 | 1 | 2 | 5 | 1 | 2 | 5 |
| 1100 | | 17 | 32 | 0 | 30 | 26 | 15 | 0 | 0 | 40 |
| 3003 | | 13 | 15 | 21 | 5 | 20 | 0 | 0 | 0 | 13 |
| 5052 | | 5 | 20 | 6 | 16 | 6 | 0 | 0 | 0 | 0 |

In looking over the data in Table 6, a number of apparent contradictions appear, i.e. in many cases maximum pit depths at one and two years are greater than at five years. Actually, no contradiction is involved, for pitting is a chance or statistical phenomenon. In other words, pitting may or may not start at any given spot at any given time. Once pitting starts, it usually proceeds rapidly for a relatively short time and then stifles itself; thus it is possible that a submerged structure may in the first few months of exposure develop a pit to a maximum depth that may not be exceeded or even equaled during succeeding years.

Because of the statistical nature of corrosion, it should be pointed out that the *maximum* pit depth of a sample is a unique and unusual figure. A plot of depth of pitting versus number of pits approaches a distribution type curve which means that the majority of pits will be found clustered around an "average" pit depth and that on the extreme end of the curve *one* or *two* deep pits may occur. These one or two deep pits are the ones listed as "maximum pit depth" and represent the extreme condition likely to be encountered.

Exposure of aluminum to tropical sea water on the Island of Aruba yielded the following data after one year.

It is interesting to note that practically all of the corrosion reported in Table 7 occurred at the point where the mounting gaskets contacted the sample. On the bulk of samples the main surface areas were free of attack or showed only a staining effect.

### SUMMARY OF SUBMERGED CORROSION DATA

From a strength standpoint, the data presented above indicate that the underwater corrosion of aluminum is slight and causes no great change in the material. Data for East River exposures shown in Table 5 illustrate a rather severe attack. Such a site, involving continuous exposure to contaminated waters, is probably not typical. Even under such a

TABLE 7
*Corrosion Resistance of Aluminum Alloys Exposed on Aruba, Continuous and Alternate immersion at Two Sites*

| Exposure | Alloy | Maximum Pit Depth* (Mils) |
|---|---|---|
| Submerged—Site 1 | 5052-H32 | < 1 |
| (stagnant sea water | 6061-T6 | 42 |
| contaminated with | 5083-O | 5 |
| refinery waste) | | |
| Alternate—Site 1 | 5083-O | < 1 |
| Submerged—Site 2 | 5052-H32 | 7 |
| (slowly flowing | 6061-T6 | 3 |
| seawater) | 6063-T6 | 48 |
| | 5083-O | 6 |
| Alternate—Site 2 | 5083-O | < 1 |

*Maximum attack at mounting holes resulting from crevice corrosion.

severe exposure the loss of properties would not result in loss of structure.

Pitting attack is so variable that maximums may range as high as 40 or 50 mils. However, this is unusual and average yearly corrosion rates are on the order of less than one mil.

### EXAMPLES OF SUBMERGED USE OF ALUMINUM

Based on the proven corrosion resistance of aluminum, this metal is used widely in boats and various marine structures. Aluminum hulls have been used for such varying applications as barges for service on the Congo River [9], Pilot dispatch boats [10] and motor yachts [11, 12]. Most recently, large (50′×100′×12′) double skin barges have been developed for service on the Ohio-Mississippi-Gulf route. The *Aluminia*, an all-aluminum coastal and river tanker 223 feet long is now operating in German waters.

Aluminum alloy 5052 used as pile sheathing showed only 14 mils penetration in 17 years of service. As a sheathing material, the outstanding use of aluminum is in the extremely corrosive Lake Maracaibo where aluminum templates are used to protect steel offshore platforms. In this application [13] aluminum showed little more than surface staining after fourteen months' exposure below the thirty-foot depth. At shallower depths, pitting to a maximum of 7 mils occurred. Comparative tests between aluminum and steel showed pitting rates after twelve months exposure of 160 mils for steel and 7 mils for aluminum (R. S. Dalrymple unpublished data).

### DESIGN CONSIDERATIONS IN USING ALUMINUM

Aluminum stands high in the galvanic series and therefore tends to corrode when coupled to most other metals under conditions where moisture can collect. This is called bimetallic corrosion and can be easily prevented.

The most simple method is to prevent moisture from entering the joint and this is readily done by

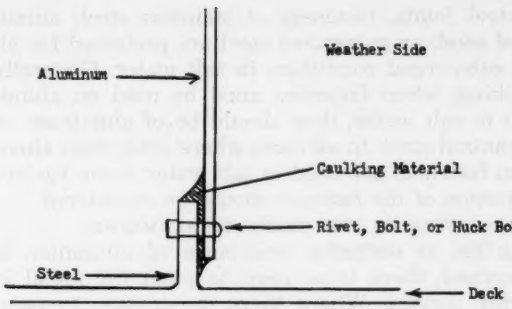


Figure 1.

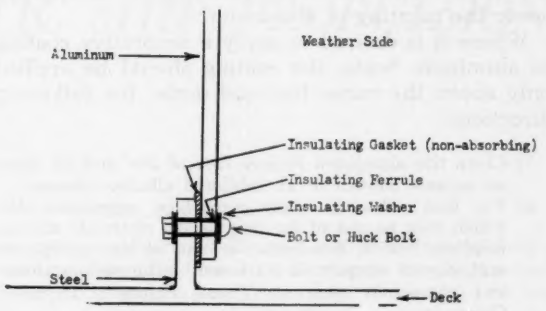


Figure 2.

caulking with a non-absorbent material. Ideally, caulking compounds (polysulfides or butyl rubber materials are excellent) are spread over the joining areas before the joint is made up. When the joint is pulled up, excess material squeezes out and can be smoothed into a fillet over the edges of the mating members. This type joint is shown in Figure 1 and is fine for aluminum to aluminum or aluminum to steel joints in all cases except total submergence in salt water. Figure 2 illustrates a joint in which complete electrical insulation of mating members is achieved. This joint may be used underwater if necessary.

Good aluminum design calls for the elimination of crevices in which moisture may collect and cause damage. When crevices cannot be designed out of a structure, caulking material, as discussed above, should be used.

It is important when insulating aluminum joints that no porous or absorbent materials be used. Only nonporous materials such as plastics, rubber or neoprene based compounds are suitable. It is also important that all joints be designed so that the weather side is self draining.

When fastening aluminum to aluminum, the use of aluminum or stainless steel fasteners is preferred. Aluminized, galvanized, or cadmium plated steel fasteners are also generally suitable. For aluminum

to steel joints, fasteners of stainless steel, aluminized steel, or galvanized steel are preferred for all but submerged conditions in salt water. Generally speaking, when fasteners must be used on aluminum in salt water, they should be of aluminum or galvanized steel. In all cases where other than aluminum fasteners are used in salt water, some surface protection of the fastener should be considered.

### SURFACE TREATMENT OF ALUMINUM

As far as corrosion resistance of aluminum is concerned, there is no need to paint the metal in marine service. Where there is occasion to paint aluminum for aesthetic reasons, the exercise of proper care will assure long lasting beauty. Special care must be used in applying anti-fouling paints to aluminum. The following instructions adequately cover the painting of aluminum:

Where it is desired to apply a decorative coating to aluminum boats, the coating should be applied only above the water line and under the following directions:

1) Clean the aluminum surface free of dirt and oil using an organic solvent or an inhibited alkaline cleaner.
2) For best adhesion, apply a surface conversion film which may be one of the proprietary materials such as Alodine, Iridite, Bonderite, or one of the phosphoric acid solvent compounds marketed by the various chemical companies such as Turco, Pennsalt, Diversey, Clepo, etc.
3) Apply one or more top coats compounded of vinyl, phenolic or acrylic resins. For longest life, at least two top coats should be applied to obtain a minimum film thickness of 3 mils.

Decorative coatings are not recommended below the water lines on aluminum vessels. Holidays (holes) in such coatings tend to localize corrosion to discreet areas resulting in penetration of the aluminum hull.

Protection coatings need be applied to aluminum hulls only under anti-fouling paints. Suitable protective coating systems for this procedure are covered by MIL specifications as follows:

1) MIL-C-15328A
   After thoroughly cleaning the aluminum surface, apply one coat of zinc chromate wash primer in a vinyl butyrate vehicle. For best results, the aluminum surface should be treated with one of the surface conversion films, such as Alodine 1200 or Iridite 14-2.
2) MIL-P-15930A
   Apply a coat of vinyl resin zinc chromate paint to obtain a one mil coating.
3) Apply 3 to 4 mils of vinyl resin top coat.
4) MIL-P-15931A
   Apply one coat of vinyl base anti-fouling paint pigmented with cuprous oxide. Caution, do not use mercury base anti-fouling paints on aluminum hulls.

Unpainted aluminum surfaces are easily and economically maintained. Boats in salt water service should be hosed off with fresh water occasionally, at least before being laid up for any extended period. Beyond this, rainfall will normally provide for sufficient washing of superstructures.

The surface should occasionally—perhaps once or twice a year—be washed or rubbed down using a sponge and scouring powder (Bon Ami, Ajax, Old Dutch, etc. will do). Such minimum maintenance will prevent accumulation of dirt, salt or extraneous matter and greatly reduce any chance pitting which might occur. Such a scouring is recommended prior to lay-up of the boat.

### CATHODIC PROTECTION OF ALUMINUM

In some cases where brass or bronze propellers are used with an aluminum boat, bimetallic corrosion will occur. This can be controlled by the use of zinc waster plates or by the use of a platinum anode impressed current system such as marketed by boat outfitters.

### SUMMARY

Aluminum alloys are admirably suited for marine applications. Alloys of 5XXX and 6XXX series are particularly adaptable to marine use, as they combine great corrosion resistance with strength and ease of fabrication.

The corrosion resistance of aluminum alloys has been repeatedly proven on a test basis. The acid test of experience in a wide spectrum of marine applications has substantiated the laboratory results and has led to a constantly expanding use of aluminum for boats, ships, marine platforms and dockside installations.

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JAMES B. FRIAUF

# *ELECTROMAGNETIC SHIP PROPULSION*

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ELECTROMAGNETIC SHIP PROPULSION, also known as magnetohydrodynamic propulsion, has recently been attracting attention of a number of inventors. It is an intriguing scheme with a number of readily apparent advantages. Among these are: (a) silence, a feature of considerable interest for submarines; (b) simplicity of structure and absence of moving parts; and (c) proven workability of the same principle in electromagnetic pumps for liquid metals [1, 2, 3, 4, 5].

But these qualitative and readily apparent advantages are accompanied by quantitative disadvantages which are not so immediately apparent. It is the purpose of this article to give a fundamental relationship relevant to electromagnetic ship propulsion and electromagnetic pumps; to check this against experimental results reported for electromagnetic pumps; and then use it to arrive at conclusions as to the feasibility of electromagnetic ship propulsion.

## THE STRUCTURE CONSIDERED

The essential parts of the electromagnetic ship propulsion arrangement considered are indicated in Figure 1 and are:

1. A horizontal water channel open at both ends extending longitudinally through the ship.
2. A magnet or other means for producing a magnetic field throughout the water channel.
3. Electrodes at each side of the channel and a source of power to send a direct current through the channel at right angles to the magnetic flux.

The arrangement described is a simple d-c motor in which the sea water in the channel is the current conductor in what corresponds to the armature circuit of a conventional d-c motor. The force caused by the action of the magnetic field on the current will push the water backward with respect to the channel (see Figure 1). We can look upon the arrangement as a jet propulsion scheme in which a sea water electromagnetic pump is used to produce

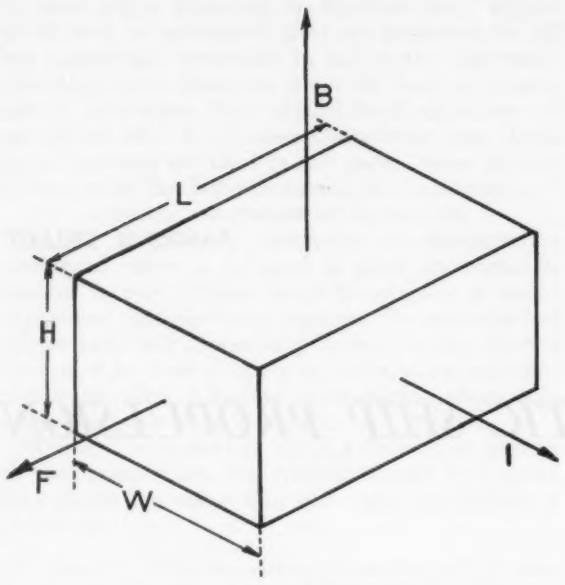


Figure 1.

the jet. The type of pump described is one which has been used for pumping liquid metals and is known as the direct-current Faraday type or the direct-current conduction type.

In order to arrive at a quantitative relationship, it will be assumed that the sea water in the channel acts like a rigid body in the conversion from electrical to mechanical power which is effected by the action of the crossed magnetic field and current; that the magnetic flux density, the current density, and the water velocity are constant in magnitude and direction at all points in the water channel and are everywhere mutually perpendicular; that there are no losses caused by "fringing" of the magnetic field or current at the ends of the channel; that the magnetic field is given to us free of any charge for power to produce the field; and that the propulsion efficiency is equal to the pump efficiency.

It should be noted that the assumptions have been made in such a way as to give a favorable rather than an unfavorable estimate of the capabilities of electromagnetic ship propulsion. This is because our primary purpose is to arrive at a reliable estimate of the maximum possible performance that can be expected from electromagnetic ship propulsion under the most favorable conditions. If this turns out to be so low as to cast a shadow on its practicability, a closer estimate is not needed.

### DERIVATION OF A FUNDAMENTAL RELATIONSHIP

We shall assume that the water channel is of rectangular cross section with dimensions as indicated on Figure 1. The back electromotive force (bemf) generated by motion of the water through the magnetic field is:

$$\text{bemf} = BWV \times 10^{-8} \text{ volts} \quad \ldots\ldots (1)$$

where B is the magnetic flux density in gausses, W is the width of the channel in centimeters, and V is the water velocity in centimeters per second.

The resistance of the water in the channel in the direction of the current is:

$$R = \frac{rW}{HL} \text{ ohms} \quad \ldots\ldots (2)$$

where r is the specific electrical resistance of the fluid in the channel in ohm centimeters, and W, H and L are channel dimensions in centimeters.

If E is the voltage applied to the electrodes at opposite sides of the water channel, the current through the water in the channel is:

$$I = \frac{E - \text{bemf}}{R} = \frac{(E - BWV \times 10^{-8})HL}{rW} \text{ amperes} \quad \ldots\ldots (3)$$

The force exerted on the water in the channel is:

$$F = BWI \times 10^{-1} = \frac{BW(E - BWV \times 10^{-8})HL \times 10^{-1}}{rW} \text{ dynes} \quad (4)$$

The mechanical power imparted to the water in the channel is:

$$P_i = FV \times 10^{-7} = \frac{BV(E - BWV \times 10^{-8})HL \times 10^{-8}}{r} \text{ watts} \quad (5)$$

The electric power input needed to do this is:

$$P_e = EI = \frac{E(E - BWV \times 10^{-8})HL}{rW} \text{ watts} \quad \ldots\ldots (6)$$

The efficiency is:

$$e = \frac{P_i}{P_e} = \frac{BWV \times 10^{-8}}{E} \quad \ldots\ldots (7)$$

The efficiency as so defined will henceforth be referred to as the electrical efficiency. It is the efficiency of the electromagnetic conversion from electrical to mechanical power in the sea water channel, that is, the mechanical power put into the water divided by the electric power input needed to produce the mechanical power. The electrical efficiency takes no account of the hydraulic losses in the water, which will reduce the useful power output of the pump, and also takes no account of whatever power may be needed to maintain the magnetic field. The electrical efficiency is thus an upper limit to the overall efficiency of the pump and of electromagnetic ship propulsion, not the overall efficiency itself.

From equation (7) it is apparent that:

$$\frac{1-e}{e} = \frac{E - BWV \times 10^{-8}}{BWV \times 10^{-8}} \quad \ldots\ldots (8)$$

and that:

$$E-BWV\times10^{-8}=BWV\times10^{-8}\left(\frac{1-e}{e}\right)\text{volts}\quad\ldots\ldots(9)$$

Substituting this value for $E-BWV\times10^{-8}$ in equation (5) gives:

$$P_i=\frac{B^2V^2\times10^{-16}\times(1-e)HLW}{re}\text{watts}\quad\ldots\ldots(10)$$

or:

$$S_i=\frac{P_i}{HLW}=10^{-16}\left(\frac{B^2V^2}{r}\right)\left(\frac{1-e}{e}\right)\text{watts cm}^{-3}\quad\ldots(11)$$

It is convenient to introduce some English units before using equation (11). When this is done it becomes:

$$s_i=2.64\times10^{-12}\left(\frac{B^2v^2}{r}\right)\left(\frac{1-e}{e}\right)\text{kw ft}^{-3}\quad\ldots\ldots(12)$$

where $s_i$ = specific mechanical power input to the water in kw $ft^{-3}$
v = water velocity in ft $sec^{-1}$
B, r, and e are in the same units as before.

### COMPARISON WITH LIQUID METAL PUMP

Equation (12) is valid for liquid metal pumps as well as for sea water pumps. It is, therefore, of interest to compare its predictions with the following data given by Jaross and Barnes [2] for a liquid sodium pump:

| | |
|---|---|
| Pumping channel size: | 6" in direction of magnetic flux<br>20.875" in direction of current<br>30" in direction of fluid flow |
| Current: | 250,000 amperes |
| Discharge: | 10,000 gpm |
| Pressure head: | 25 psi |
| Magnetic flux density: | 4,000 gausses |
| Efficiency: | 0.20 (approximately) |

From the data tabulated above, we can readily calculate the following additional information:

| | |
|---|---|
| Fluid velocity | 25.6 ft $sec^{-1}$ |
| Volume of pumping channel | 2.18 $ft^3$ |
| Useful power output (10,000 gpm at 25 psi): | 109 kw |
| Specific mechanical power output: | 50.0 kw $ft^{-3}$ |

Now substitute into equation (12), B=4,000 gausses, v=25.6 feet per second, and $r=20\times10^{-6}$ ohm cm, the specific resistance of liquid sodium at the temperature at which it was used. The result is:

$$s_i=1383(1-e)/e\quad\ldots\ldots(13)$$

We do not yet know the electrical efficiency, e, but it seems reasonable to suppose that the overall efficiency, 0.20 is equal to e x e* where e* is an efficiency that takes into account the hydraulic friction loss and all other losses. Furthermore, the specific power output is 50.0 kw per cubic foot. Making use of these two pieces of information gives e=0.865 and e*=0.231. Substituting this value of e in equation (13) gives $s_i$=216 kw per cubic foot. While this comparison with experimental results can hardly be considered a complete verification of equation (12), it furnishes ample experimental support for one of the predictions from this equation, namely, that the specific power input to the fluid can be very high even for high electrical efficiency if the fluid being pumped has a specific resistance as low as that of liquid sodium.

### APPLICATION TO SEA WATER PUMPS

The situation is altogether different for sea water pumps. When we substitute into equation (12), r=20 ohm cm, the specific resistance of sea water the result is:

$$s_i=1.32\times10^{-13}B^2v^2(1-e)/e\quad\ldots\ldots(14)$$

Computed values of $s_i$ for different values of B, v, and e are given in Table I, in which the unit for the Bv product is gauss ft $sec^{-1}$.

TABLE I

| e | Bv=$10^2$ | Bv=$10^4$ | Bv=$10^6$ | Bv=$10^8$ |
|---|---|---|---|---|
| 0.99 | $1.33\times10^{-9}$ | $1.33\times10^{-7}$ | $1.46\times10^{-4}$ | $1.33\times10^{-3}$ |
| 0.90 | $1.46\times10^{-8}$ | $1.46\times10^{-6}$ | $1.19\times10^{-2}$ | $1.46\times10^{-2}$ |
| 0.50 | $1.32\times10^{-7}$ | $1.32\times10^{-5}$ | $1.31\times10^{-1}$ | $1.32\times10^{-1}$ |
| 0.10 | $1.19\times10^{-6}$ | $1.19\times10^{-4}$ | $1.33\times10^{-5}$ | 1.19 |
| 0.01 | $1.31\times10^{-5}$ | $1.31\times10^{-3}$ | $1.32\times10^{-2}$ | 13.1 |

It is immediately apparent from Table I that for a sea water pump reasonably high electrical efficiency is accompanied by intolerably low specific power input to the water in the pumping channel, and that high specific power input is accompanied by intolerably low electrical efficiency. This highly undesirable combination of characteristics seriously limits the performance of electromagnetic ship propulsion. To see this it is instructive to make a few estimates for pumps such as might be used for ship propulsion. The starting parameters chosen are:

*Mechanical power input to the water=1,000 kw.* This is very small for a propulsion installation, particularly since only a part of this input will be available for propulsion because of hydraulic losses. Even so, the water channel turns out to be huge.

*Magnetic flux density=5,000 gausses.* This is more than the flux density in the liquid sodium pump described by Jaross and Barnes and is considerably higher than is practical for the large volume needed for a sea water pump. It will be used, however, in view of our objective of estimating the maximum possible performance of electromagnetic ship propulsion under the most favorable conditions.

*Electrical efficiency, e=0.15.* This is a low efficiency but the volume of the water channel is large. It would be even larger for a higher efficiency.

*Cross section of channel.* Calculations for the pumps of Table II are based on a pumping channel which is square in cross section, W feet on a side.

TABLE II

*Calculated performance of d-c Faraday type electromagnetic pumps for sea water*

| | *Pump I* | *Pump II* |
|---|---|---|
| *For both pumps* | | |
| Mechanical power input to water, $P_i$, kw | 1,000 | |
| Velocity of water, v, ft $sec^{-1}$ | 40 | |
| Force exerted electromagnetically on water, F, pounds | 18,430 | |
| Magnetic flux density, B, gausses | 5,000 | |
| Electrical efficiency, e | 0.15 | |
| Water channel volume, $W^2L$, $ft^3$ | 33,400 | |
| W, ft | 28.8 | 38.4 |
| L, ft | 40.2 | 22.7 |
| I, amperes | 18,660 | 14,020 |
| IR, volts | 304 | 405 |
| E, volts | 357.6 | 476.4 |
| $EI \times 10^{-3}$, electric power input, kw | 6,660 | 6,660 |
| Hydraulic efficiency | 0.20 | 0.40 |
| Useful power output, kw | 200 | 400 |
| Overall efficiency | 0.03 | 0.06 |

Both pumps illustrate the disadvantages of electromagnetic ship propulsion, enormous volume even for small power output, and low efficiency. Nor, as can be seen from equation (12), can anything be done about it unless the $B^2v^2/r$ factor can be substantially increased. There are only three ways to increase this factor, increase B, increase v, or decrease r.

The magnetic flux density of 5,000 gausses assumed for Table II is already well above what would be feasible for the large water volume needed. To produce the magnetic field assumed for Table II by means of permanent magnet material would require more than 30,000 tons of Alnico V, one of the high performance permanent magnet materials with a maximum energy product of $5 \times 16^6$ gauss oersteds. Nor, although detailed calculations have not been made on this point, does it seem likely that too much would be gained by going to field coils since these would require not only a considerable weight of copper and soft iron for the coils and magnetic structure but a continuous expenditure of fuel to produce the power needed to energize the coils. Unless there is some unforeseen breakthrough which makes it possible to produce very large magnetic fields over large volumes of sea water, it does not appear that electromagnetic ship propulsion can be made practical by increasing B.

Increasing v would be as effective as increasing B, but the hydraulic losses mount up fast as v is increased and limit what can be done in this way. A study of this problem indicates that either the magnetic flux density or the channel cross section must be increased as v is increased if neither the hydraulic nor the electrical efficiency is to decrease. It appears, therefore, that an increase in v would necessarily lead also to an increase in B or W, both of which would be undesirable.

The sole remaining alternative is to decrease r, the specific resistance of sea water. It has been suggested by some of the proponents of electromagnetic ship propulsion that r be decreased by injecting into the water channel some ingredient that would decrease the resistivity of sea water. Unfortunately, these suggestions have not been accompanied by any instructions on how to make the necessary ingredient. If we knew how, electromagnetic ship propulsion might begin to look attractive.

As things are, it does not look attractive. It illustrates once again the well known proposition that a high efficiency electric motor of reasonable size simply cannot be built by using a conductor of high resistivity. And sea water is of very high resistivity indeed when one is talking in terms of conductors. Its resistivity is about one million times that of the liquid sodium that is being pumped in some of the electromagnetic liquid metal pumps. A factor of a million is enough to make the difference between a pauper and a millionaire. It is not surprising that such a factor will make a corresponding difference in electromagnetic pumps.

## CONCLUSIONS

The purpose of this study has been to estimate an upper limit to the performance of electromagnetic ship propulsion on the basis of highly favorable assumptions. The conclusions reached are that:

(1) This limit is so low that electromagnetic ship propulsion is highly unattractive. The resistivity of sea water being what it is, practically realizable values of B and v give values of $B^2v^2/r$ so small that electromagnetic ship propulsion will be bulky and inefficient.

(2) The only ways to remedy this situation are to decrease r, increase B, or increase v. Nothing now visible on the horizon indicates that any one or any combination of these factors can be changed enough to make electromagnetic ship propulsion look attractive. Of course there may at some time be a breakthrough which will change the picture. Until then, the prospects for electromagnetic ship propulsion look bleak.

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"REED'S MARINE EQUIPMENT NEWS"

# *MARINE APPLICATION FOR EPICYCLIC GEARING*

**ACKNOWLEDGMENT**

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THE TRUTH of the old adage, "necessity is the mother of invention," has been proved many times over, and while engineers are interested in obtaining the maximum output of energy from a minimum input, inventions will continue in ever increasing numbers. Perhaps it is not exactly time to class the application of epicyclic reduction gears to marine propulsion as an invention, but rather the development of a process. This development has been brought about by the need for Shipowners and Shipbuilders to find ways and means of operating ships more economically.

Their quest is for a means of transmitting high powers for long periods, with machinery giving low power-weight ratios, and occupying as small a space as possible, commensurate with great reliability and ease of maintenance. A landmark in the search for such machinery will be represented by the introduction, later this year, of the Australia—Tasmania cargo vehicle ferry *Bass Trader*. The power plant of this vessel will be distinctive, due to the use of three comparatively modern developments in ship propulsion; namely the use of two Napier Deltic 18-cylinder high-speed diesel engines, coupled to Allen-Stoeckicht epicyclic gears through 'Fluidrive' hydraulic couplings. Each gearbox output shaft is solidly coupled to a propeller shaft, driving a Stones' Ka Me Wa variable pitch propeller, which is used for reversing.

The essential difference between epicyclic and the conventional parallel shaft gear is that, in an ordinary train the axes of the wheels are fixed, but in an epicyclic train, at least one axis moves round another axis which is fixed. The basic elements of the gears are as follows:—(1) A central sun-wheel. (2) An internally-toothed gear ring (usually termed the annulus). (3) A planet carrier. (4) Planet wheels (these wheels revolve on the planet carrier spindles and engage with the sun-wheel and annulus). The first three of the above basic elements may be arranged so that any one of them (1, 2 or 3) is held stationary. The effect of this is to determine the minimum and maximum ratio for which the gear is suitable, and also the direction of rota-

tion of the output shaft relative to the input shaft.

One of the greatest problems which has had to be overcome in the development of suitable epicyclic gears is the necessity of ensuring that all the planets uniformly share the load being transmitted.

When a torque is applied to a stationary gear having three planet wheels, equal load sharing can be ensured by allowing either the sun-wheel, the annulus, or the planet carrier to float, since the forces involved will move the free member until it is in a position of equilibrium. This is attained only when the tooth loads on all members are identical.

Due to unavoidable errors in the manufacturing process and elastic deformation of the material when under load, load sharing under running conditions becomes an extremely complicated design problem. It must be realized that the time between tooth contacts will only be of the order of ten-thousandths of a second, and thus an error of only 0.0001 inch between adjacent teeth (and this would be a very accurate gear) can cause considerable accelerating forces on the wheel. In order to overcome this problem, the annulus is designed to have sufficient flexibility to enable it to absorb any minor inaccuracies, thus giving perfect load sharing between the planets. In addition, the annulus is flexibly connected to the shaft or gear case by means of a double-tooth-type flexible coupling.

Resistance wire strain gauges, mounted on the outer surface of the annulus of a planetary-type gear, have proved beyond all doubt that this arrangement equalizes the load satisfactorily. The idea is just as effective in ensuring equal load sharing between the planets of gears having more than three planet wheels.

The gears for the *Bass Trader* have been designed on a long-life basis and to the requirements of Lloyd's Register of Shipping, to transmit 2,030 hp each continuously, with a speed reduction of 1,580 to 175 rpm, and for a six-hour rating of 2,182 hp, running at an input speed of 1,630 rpm, reducing to 181 rpm.

The general arrangement of the gear is shown diagramatically in Figure 1; it will be seen that the first gear train is of the star type, in which the planet carrier is held stationary, and the annulus rotates in the opposite direction to the sun-wheel. The sun-wheel is connected to the high-speed shaft and the annulus to the low-speed shaft (Figure 2).

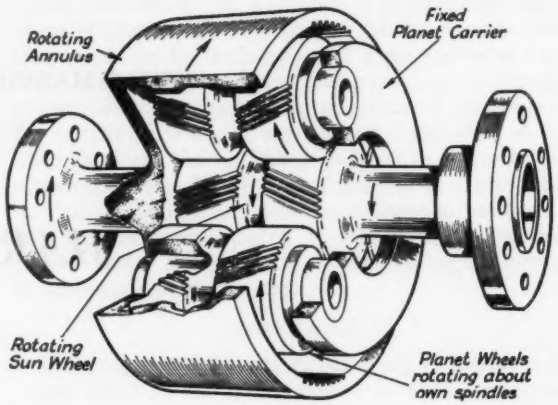


**Figure 2.**

The second train is of the planetary type, in which the annulus is fixed to the casing and the planet carrier rotates in the same direction as the sun-wheel. The sun-wheel is connected to the high-speed shaft, and the planet carrier to the low-speed shaft (Figure 3).

A section through the gear and its detailed construction can be seen in Figure 4. The sun-wheel of the first train is connected to the "Fluidrive" coup-

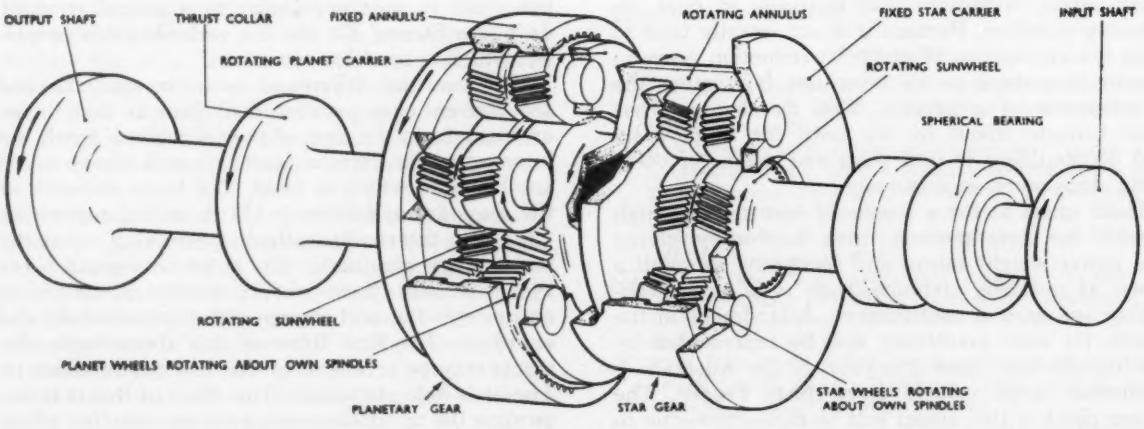


**Figure 1.**

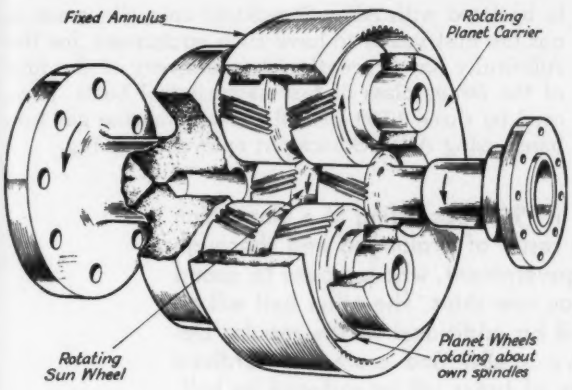


**Figure 3.**

ling by a double-toothed flexible-coupling sleeve and stub shaft. The stub shaft is solidly bolted to the "Fluidrive" output shaft and runner, the assembly being supported by one bearing in the coupling and by the spherically-seated bearing within the gear case. The four planet wheels revolve on white metal-faced spindles and are driven by the floating sun-wheel. The planet wheel spindles are held in the planet carrier, which is rigidly bolted and dowelled to the gear-case. The rotating annulus system is flexibly coupled to the gear-case by a single solid forged collar on the output shaft, the load being taken on a Michell thrust bearing.

The gear unit is extremely compact and its weight is about 5½ tons, both factors being the primary characteristics which show the advantages of these gears over conventional parallel shaft drives.

The oil for the two gears is supplied from a common drain tank by a motor-driven oil pump, this and the duplicate stand-by pump being each driven by a 415 volt 3-phase, 60-cycle motor. The pumps draw oil through separate suction strainers and discharge it through a screw down valve to a common

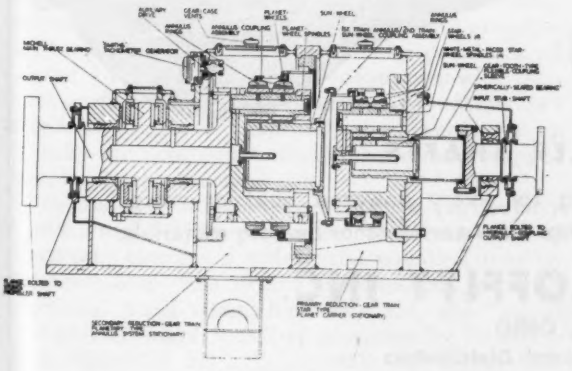

**Figure 4.**

delivery main, having a duplex oil filter and a magnetic filter. After the filters, the line branches, and an oil cooler is provided for each gear. The proportion of the oil passing through the cooler is controlled by a thermostatically-operated valve, maintaining the oil at a temperature of 120°F.

From the cooler, oil is piped to the high-speed bearing, the annular groove in the star carrier, and to the low-speed journal bearings and the thrust bearing. The oil then flows through drillings to lubricate the planet and star spindles and gear teeth.

Another problem which had to be overcome was the fact that the gears are of a double-helical type, which incidentally are now offered as standard, in place of the former spur or single-helical type, thus provision had to be made to ensure that each of the two helices takes its share of the load. This is achieved by the correct design of the two annuli and the use of a double-gear tooth-type coupling for the connection of these annuli to each other and to the rigid member. Further, freedom of the floating pinion and of the two planets to move axially as may be required, also assists in this load equalization. The axial freedom is helped by the use of a light double-gear-toothed flexible coupling between the sun-wheel and the shaft of the high speed machine. The sun-wheel is not supported in bearings, but is located by the planet wheels. The extremely low inertia of all the parts, compared with those of an equivalent parallel shaft gear, helps further in an even load distribution between the two helices. The sun and planet wheels are normally of Nitralloy. After hobbing or planing, followed by shaving, the wheels are nitrided.

The planet wheels have ground and polished bores which run on white metal faced steel spindles. This method of forming the planet wheel bearings ensures that the load on the white metal is always in one direction and eliminates any possibility of the white metal failing from fatigue.

The annulus and coupling rings are made of carbon or alloy steel forgings, suitably heat-treated. Due to the fact that the surface stress on the annulus teeth is much lower than on the sun and planet wheels, it is rarely necessary to harden the annulus rings.

Since the radial components of tooth loads are all balanced, only torque reaction needs to be taken on the gear-case. For normal conditions, the gear-case is constructed of fabricated steel, fully annealed after welding, and is usually split on the horizontal center line, so that the gear internal assembly can be removed without disturbing the bottom half of the case. As the sun-wheel coupling sleeve can be disconnected from the sun-wheel coupling flange without disturbing the shaft of the high-speed machine, and the planet carrier can be disconnected

from the low-speed shaft without lifting the low-speed shaft gear, it is possible to remove the gear internals without disturbing the alignment of either the high or low-speed machines.

The *Bass Trader*, although the first merchant ship to be fitted with Allen-Stoeckicht epicyclic gears, is not the first vessel to have such equipment, for the Admiralty have recently taken delivery of the first of the *Brave* class of fast naval patrol boats, powered by three 3,500 Bristol Proteus marine gas turbines using Allen-Stoeckicht epicyclic gearing.

Norway will have a brand-new Navy in 1968, according to a plan which has now been published. The plan, the result of prolonged and thorough study, has now been endorsed by the government, who propose to spend half of the estimated £42 million cost on new ships. The other half will be paid by the United States. The sum will be additional to the regular Defence Budget. The intention is to have smaller and more standardized ships but in larger numbers. The variety of types will be reduced by half, while the number of ships in continuous service will increase by 100 per cent. The building program comprises five destroyer escorts, five patrol craft, 15 submarines and 31 motor torpedo and gun boats. The total number of ships by 1968 will be 93. The object of the new plan is to provide for a basic naval force which can keep continuous watch and guard against possible invasion from the sea. No ship will ever be lying idle at its moorings. The plan involves a considerable increase in the number of officers and ratings.

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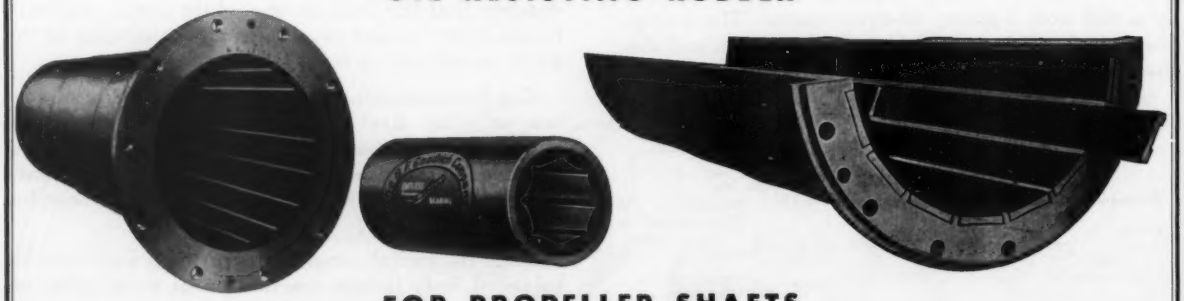

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# *ENGINEERING APPLICATIONS OF THE SIGNAL FLOW GRAPH*

**THE AUTHOR**

*graduated from the U.S. Naval Academy in 1953. His shipboard assignments have included tours as Gunnery Officer aboard the USS SHELTON (DD 790), and as Missile Guidance Officer aboard the USS TUNNY (SSG 282), where he was designated qualified in submarines. He reported to MIT in June 1957 for the Naval Construction and Engineering post-graduate course, and has recently completed requirements for a Doctor of Science degree in Electrical Engineering at MIT.*

A FIRE CONTROL radar tracking an aircraft, a voltage regulator trying to counteract the effect of a suddenly-applied electrical load, a diesel engine vibrating on its foundation—these examples are seemingly separate engineering problems, but the equations which govern their behavior are strikingly similar. Since World War II increasing attention has been focused on these and similar problems, all related by linear differential equations with constant coefficients. A body of knowledge—sometimes called the "systems" approach—has been built up to unify the approach to the analysis and design of complex linear devices.

The Laplace transform has been a particularly efficient tool for these dynamic problems, since it effectively changes a differential equation into an algebraic one. This article is concerned with an additional (and complementary) aid, the "signal flow graph," which was first presented by Professor S. J. Mason of M. I. T. in 1953. The signal flow graph is basically a "picture" of a set of linear algebraic equations which (1) shows the interactions among all the variables, (2) stresses cause-effect relationships within the device, and (3) allows speedy solution of system response to various excitations.

In the following paragraphs, simple algebraic equations will first be analyzed using the flow graph. Then, after the mechanics of drawing and solving the flow graph have been presented, differential equations of increasing complexity will be solved. Next, an algebra for systems which operate only at discrete instants of time will be developed, with pertinent naval examples. Finally, an interesting topic of probability theory, the Markov process, will be examined using the signal flow graph.

It is hoped that the reader, although possibly not concerned with the particular examples solved in this paper, can detect a similarity of approach in every case and extend the ideas expressed to his own problems, whether in vibrations, nuclear reactor dynamics, or ship motion.

### FUNDAMENTAL OPERATIONS

The word linear, when applied to a physical device or to an equation, implies that the magnitude of the "effect" (or dependent variable) is directly proportional to the magnitude of the "cause" (or independent variable). That is, if a force of three pounds causes an acceleration of 3 ft/sec$^2$, we expect that a force of six pounds will cause an acceleration of 6 ft/sec$^2$. The "system," in this example, is a mass of 1 slug, which completely specifies the ratio of all possible force-acceleration pairs.

In a like manner, the signal flow graph attempts to show the properties of a linear system regardless of the magnitudes of the particular variables concerned. For a simple example, suppose we are interested in a device whose output c is the weighted sum of two input quantities, such that

$$c=3a+2b$$

A signal flow graph of this equation is shown in figure 1. We interpret this picture as follows: The signal or quantity at the "node" a is multiplied by 3 and added to twice the signal at the node b to form the variable c. The two paths to node c are known as "transmissions" and are unilateral, in that they only permit signal to flow in the direction of the arrow. Suppose we "apply" a quantity 3 to node a and a quantity 4 to node b. The signal at node c is thus $3\cdot3+2\cdot4=17$.

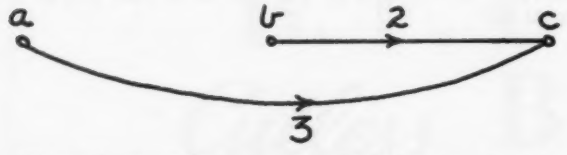


**Figure 1. Signal flow graph of a simple linear equation, 3a+2b=c.**

With this example in mind, we can formulate the main rules for construction of a flow graph. A variable at a particular node has a value equal to the sum of all input signals to the node, each input signal being the value of the variable at the originating end of the transmission, multiplied by the value of the particular transmission. An output node will have no transmissions from it, and an input node will have no transmissions to it.

In example, we next consider the set of equations:

$$3a+2b=c$$
$$4a+2b+c=b$$

A corresponding flow graph is shown in Figure 2. The form of this flow graph is not unique, but is drawn to indicate that a is the dependent variable. Directly solving this simple pair of equations, by eliminating b, yields $c=-\frac{5}{3}a$. How can this effective

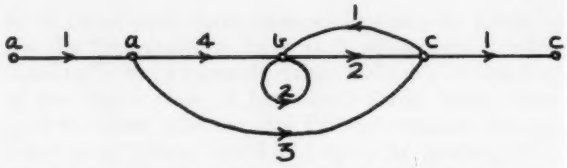


**Figure 2. Signal flow graph of equations: 3a+2b=c and 4a+2b+c=b with a as cause and c as effect.**

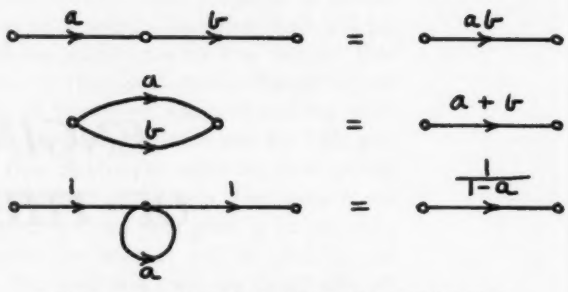


**Figure 3. Basic steps in flow-graph manipulation.**

transmission, $-5/3$, from a to c be found from the flow graph of Figure 2? One method is by "step-by-step" flow graph reduction, which rearranges the form of the graph until a simple configuration is reached which can be solved by inspection. Before outlining this approach, several simple rules for manipulation are presented in Figure 3.

The top two identities of Figure 3 are obvious from the equations they represent. If x is an input variable, y an intermediate variable, and z is an output variable, the first identity says that $y=ax$ and $z=by$ is equal to $z=abx$. The second relationship indicates that $z=ax+bx=(a+b)x$. The third identity is very important, but cannot be easily seen by inspection. $y=x+ay$ and $z=y$. Eliminating y,

$$z=\frac{1}{1-a}x.$$

The strategy of flow graph reduction is to remove all feedback loops, such as c-b-c (indicating the path from node c, through node b, and back to c) in Figure 2, and leave only self loops, such as b-b.

The philosophy behind this particular step is that since c and a are the variables of interest, output and input, we need only preserve these two and can alter any intermediate structure as long as the value at node c is preserved. The signal leaving along the path c-b is modified in some fashion by the flow graph structure at node b, and returns to c only along the path b-c. The only other signal along b-c is the contribution from a. Because of linearity, we may consider each component separately and superimpose the results. Thus, $\frac{1\cdot2}{1-2}=-2$

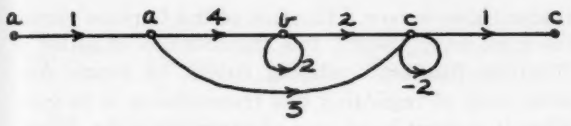


**Figure 4. Flow graph of Figure 2 with loop c-b-c changed to self-loop around node c.**

(from the first and third identities of Figure 3) is the value of the transmission from c back to itself. This is made a self loop at c and the transmission c-b is removed, as shown in Figure 4. A negative sign for a transmission does not change the direction of the flow.

At this point, the overall transmission a-c is seen to be the paths of a−b−c+a−c, all passing through the self-loop at c. That is,

$$T_{ac}=\frac{\frac{4\cdot 2}{1-2}+3}{1-(-2)}=-\frac{5}{3}$$

using all the identities of Figure 3.

An even faster method, which will be presented without proof, has been developed by Mason. It permits reduction by inspection of even very complicated flow graphs. The formula is

$$T_{jk}=\frac{\sum_i P_i \Delta_i}{\Delta}$$

where $T_{jk}$ is the transmission from node j to node k.

While the statement of this formula is formidable in mathematical symbology, its execution is generally simple in practice. The basic element is a loop, which refers to any closed path around which signal can flow without crossing the same node twice (such as b-c-b in Figure 2). Non-touching loops refer to loops which do not share any common node. $\Delta$ is defined as 1− (sum of all possible loop transmissions) + (products of all possible pairs of non-touching loop transmissions) − (products of all possible non-touching triplets) . . . etc. $P_i$ is any separate path from node j to k, over which no node is crossed more than once. $\Delta_i$ is defined just as $\Delta$, except that only loops which do not touch any part of $P_i$ are considered.

To illustrate this technique, let us reanalyze the flow graph of Figure 2.

$$T_{ac}=\frac{\sum_i P_i \Delta_i}{\Delta}$$

There are only two loops in the flow graph, b-b and b-c-b, and both touch at node b. Hence, $\Delta=1-(2+2)$. $P_1=1\cdot4\cdot2\cdot1$ and there are no loops which don't touch $P_1$ so $\Delta_1=1$. $P_2=1\cdot3\cdot1$ and there is one loop which doesn't touch $P_2$, b-b, so that $\Delta_2=1-(2)$. Accordingly

$$T_{ac}=\frac{1\cdot4\cdot2\cdot1+1\cdot3\cdot1(1-2)}{1-(2+2)}=-\frac{5}{3}$$

Another more complicated example (Figure 5) will illustrate the utility of this method. The transmission is:

$$T_{jk}=\frac{1\cdot2\cdot4+1\cdot2\cdot7\cdot3+1\cdot6\cdot3}{1-(1\cdot6\cdot5+1\cdot2\cdot7\cdot5+4\cdot8+3\cdot8\cdot7)+(1\cdot6\cdot5)(4\cdot8)}=\frac{68}{661}$$

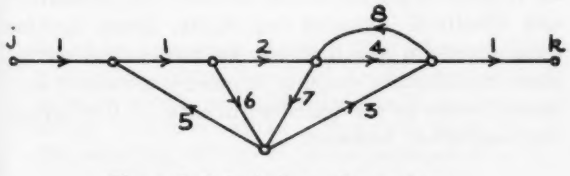


**Figure 5. A typical complex system.**

After experience has been gained in the reduction of flow graphs, it is possible to appreciate the value of having a single expression for the transmission between input and output nodes for even very complex systems. There are rarely more than three mutually non-touching loops in ordinary flow graphs of engineering usefulness, so the magnitude of the desired result is not unmanageable.

## APPLICATIONS TO DIFFERENTIAL EQUATIONS

The flow graph would merely be of academic interest if its use were restricted to simple numerical equations in the above examples, which were used to illustrate the methods of reduction. Its true field of application is in analysis of systems whose behavior is approximated by linear difference or differential equations. As a trivial illustration of a system of this type, suppose we are interested in the voltage developed across the capacitor of Figure 6, when the circuit is excited by an arbitrary voltage source e(t). The Laplace transform is of great

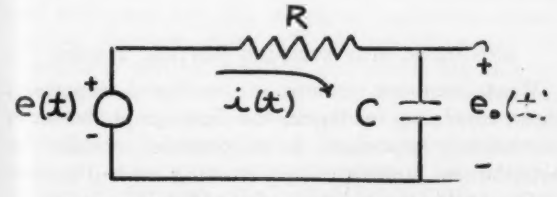


**Figure 6. Simple resistor-capacitor network.**

TABLE I. *Several basic Laplace transform pairs*

| f(t) | F(s) |
|---|---|
| $\frac{d}{dt}\left[f(t)\right]$ | $sF(s)-f(o)$ |
| $\int f(t)dt$ | $\frac{1}{s}\left[F(s)+\int f(t)dt\vert_{t=o}\right]$ |
| $e^{-at}$ | $\frac{1}{s+a}$ |
| $tf(t)$ | $-\frac{d}{ds}[F(s)]$ |
| $1$ | $\frac{1}{s}$ |
| $f(t-T)$ | $e^{-Ts}F(s)$ |

utility in this class of problem. Defined by

$$L[f(t)]=\int_0^\infty f(t)e^{-st}dt=F(s)$$

the transform approach converts a differential equation into an algebraic problem. Table I lists several of the basic transform pairs. The resistor-capacitor circuit is redrawn with Laplace notation in Figure 7, where the complex impedance of the capacitor is $\frac{1}{sC}$, and the source voltage is a function of s. Solving for $E_o(s)$:

$$E_o(s)=\frac{\frac{1}{sC}}{R+\frac{1}{sC}}$$

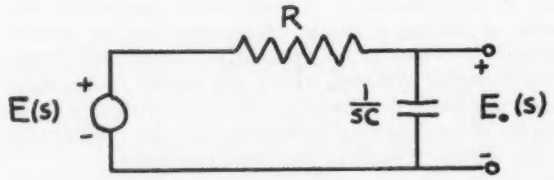


**Figure 7. Simple resistor-capacitor network expressed in transform notation.**

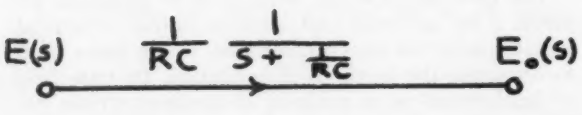


**Figure 8. Flow graph of resistor-capacitor network of Figure 6 and 7.**

This relationship is shown in Figure 8, where the transmission is now a function of the Laplace variable s. In servo theory, this transmission is called a "transfer function" relating output to input. Another way of regarding this transmission is to consider it a short-hand way of expressing the differential equation which relates the two variables, with the operator s replacing $\frac{d}{dt}\left[\quad\right]$.

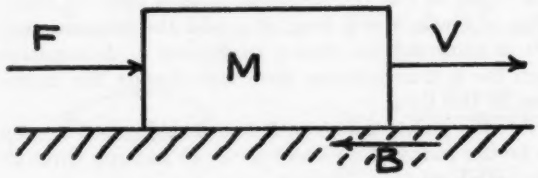


**Figure 9. Mass with friction being accelerated under external force.**

Another simple example to illustrate these ideas is shown in Figure 9. Here is shown a mass M which is subjected to a dynamic force F and a friction of force of B times the velocity. Hence,

$$F(t)=M\frac{dv}{dt}+Bv \text{ or } F(s)=(Ms+B)\,V(s) \text{ and}$$

$$\frac{V(s)}{F(s)}=\frac{1}{M}\,\frac{1}{S+\frac{B}{M}}.$$

The flow graph for this system is shown in Figure 10. In view of the similarity between the mechanical and electrical dynamic equations, some authors have devised a circuit theory for mechanical spring, mass, and dashpot systems. A more satisfactory similarity exists in the transfer function of flow graph representation, however.

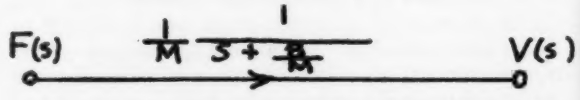


**Figure 10. Flow graph of mechanical system of Figure 9.**

### AUTOMATIC SHIP STEERING CONTROL SYSTEM

When complex systems are analyzed, especially those involving feedback, the flow graph becomes increasingly important. As an example, consider the hypothetical automatic ship steering control system of Figure 11, shown in functional form.

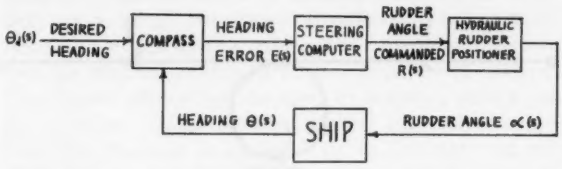


**Figure 11. A hypothetical shipboard automatic steering control system.**

References on hydraulic control show that a transfer function of the form $\frac{K_2}{s(s^2+cs+d)}$ exists between input command and output position for a typical hydraulic ram positioning system. Mechanical feedback will be used from the output position of the ram tending to cancel the input command. The rudder angle $\alpha(s)$ will induce a proportional moment on the ship about the yaw axis. Hence $K_3\alpha(s) = J_s{}^2\theta(s) + Bs\theta + D\theta$, where J is the effective moment of inertia of the ship in yaw, B is the effective damping term, and D accounts for the stabilizing or destabilizing effect of the ship's hull for a perturbation in heading.

Finally, the steering computer is designed in order to improve the characteristics of the system. One possible configuration might be an electronic amplifier in series with a resistor-capacitor network with overall transfer function of the form $K_1\frac{s+a}{s+b}$. The flow

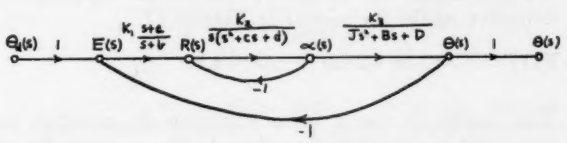


**Figure 12. Flow graph of automatic steering control system of Figure 11.**

graph for this system is shown in Figure 12. Using the flow-graph reduction formula:

$$\frac{\theta(s)}{\theta_d(s)} = \frac{K_1\frac{(s+a)}{(s+b)}\frac{K_2}{s(s^2+cs+d)}\cdot\frac{K_3}{(Js^2+Bs+D)}}{1-\left[-K_1\frac{(s+a)}{(s+b)}\frac{K_2}{s(s^2+cs+d)}\frac{K_3}{(Js^2+Bs+D)}-\frac{K_2}{s(s^2+cs+d)}\right]}$$

This rather rapid example was not designed to offer much insight into the design of an automatic rudder control system. Rather, it shows (1) typical transmissions to be found in physical equipment and (2) that the earlier reduction formula applies equally well to transmissions which are functions of s. The frightening appearance of the result of this reduction, $\frac{\theta(s)}{\theta_d(s)}$, would be just as frightening if arrived at by any other method. The major problem of automatic control has been to develop methods of analysis which will yield the significant dynamic behavior of such a system without the need for arduous factoring of high-order polynomials of s.

## DISCRETE SYSTEMS

Up to this point, we have been concerned with quantities such as voltages or torques which are continuous functions of time. In many cases discrete variables are the quantities of interest. Several examples are: (1) A digital computer operating on discrete data. (2) A search radar set "sampling" contact position and delivering this information at periodic intervals. (3) A submarine commander making periodic periscope observations on target and escort during a submerged approach, and (4) the probability distribution of possible values of the sum of a rolled pair of dice—a sequence of probabilities corresponding to integers from two to twelve.

A method of transform analysis, using the flow graph, has been developed to aid in the study of systems which operate with periodic data. The quantities handled can be considered as pure numbers which are indexed in time, with a period of T time units. Figure 13 shows a typical train of data or "signal."

Under the constraint of linearity, we may add, subtract, amplify, attenuate, or delay signals. The

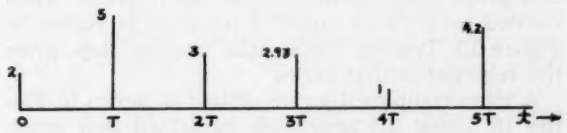


**Figure 13. A typical discrete signal.**

**Figure 14. Characteristics of the z operator, or unit delay.**

fundamental operator is z, which delays a signal one period. For example, Figure 14 shows a signal of unit value occurring at n=1 (or n=1 T) in time, which passes through a flow graph with a transmission of z. The output signal has the same magnitude but occurs one unit later, at n=2.

Just as a system can be expressed as an algebraic function of the operator z, such as the pure delay system above, so can an input or output signal be expressed in the "z-transform" domain defined as follows:

$$F(z)=\sum_{n=0}^{\infty} f(nT)z^n$$

To illustrate the formation of these transforms, consider again the signal of Figure 13:

$$F(z)=2+5z+3z^2+2.93z^3+1.0z^4+4.2z^5$$

The power of the z term indicates its position in time and its magnitude refers to the magnitude of the signal at that time. Another example would be the input signal of Figure 14, z, which is operated on by the delay z to yield an output of $z^2$. It is no accident that the output transform of this simple system is the product of the system and input transforms: it is always true for linear systems. In fact, if the signals considered to be impulses (Dirac delta functions) spaced equally in time, the z-operator is merely shorthand for the Laplace time-shifting transform $e^{-sT}$, as previously given in Table 1, and all the properties of the continuous Laplace transform carry over into the discrete case.

A discrete signal which is of fundamental importance is the geometrically decaying series: $1+az+a^2z^2 \ldots$ corresponding to a time signal of $a^n$, $n=0, 1, 2, \ldots$ The transform can be written in closed form as $\frac{1}{1-az}$ as can be checked by dividing the denominator into the numerator. This decaying series turns out to be the basic behavior of linear discrete systems, just as exponential decay characterizes the natural response of continuous systems. A flow graph which would exhibit this response, when excited by a "unit input" 1, at n=0, is shown in Figure 15. Tracing the signals, step by step, gives the required output series.

A more complex discrete system is shown in Figure 16. Using the previously explained flow graph "one-shot" reduction procedure, the overall transmission is

$$\frac{z\cdot\frac{1}{2}\cdot\frac{5}{3}}{1-\left[\cdot z\frac{1}{2}\cdot\frac{5}{3}-\frac{1}{2}\cdot\frac{1}{3}z^2\right]}$$

$$=\frac{\frac{5}{6}z}{\left(1-\frac{1}{3}z\right)\left(1-\frac{1}{2}z\right)}$$

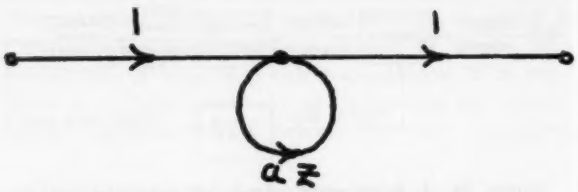


Figure 15. Simple geometrically decaying system.

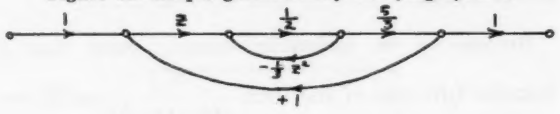


Figure 16. Typical discrete system.

If a unit step input of $\frac{1}{1-z}$ is applied, the output signal is $\frac{\frac{5}{6}z}{(1-z)\left(1-\frac{1}{3}z\right)\left(1-\frac{1}{2}z\right)}$

(because of the multiplying nature of z-transforms) which can be broken up by partial fractions into $\frac{\frac{5}{2}}{1-z}+\frac{\frac{5}{2}}{1-\frac{1}{3}z}-\frac{5}{1-\frac{1}{2}z}$

Thus,

$$\text{Output (nT)}=\frac{5}{2}(1)^n+\frac{5}{2}\left(\frac{1}{3}\right)^n-5\left(\frac{1}{2}\right)^n$$

$(n=0, 1, 2\ldots)$

The "unit step" $\frac{1}{1-z}$ is a train of unit signals beginning at n=0. It has been found convenient to use the unit step as a test input to discrete systems to evaluate transient behavior. For example, Figure 17 shows the input and output of this system, indicating a slow approach to the steady-state value.

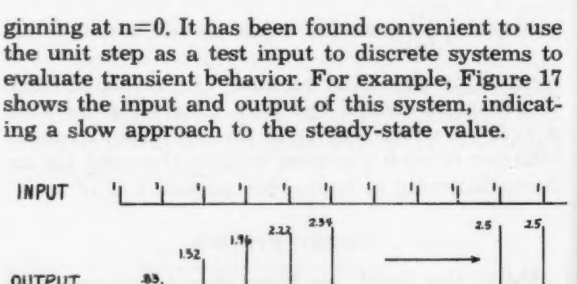


Figure 17. Step response of discrete system of Figure 16, showing transient and steady-state behavior.

Discrete systems have been discussed in the abstract sense. It will be helpful to consider now a hypothetical physical problem which is well approximated by a linear discrete model.

Suppose that a submarine tender is responsible for supplying diesel engine cylinder liners to a particular submarine squadron. The first of each week liners are either drawn from or turned in to a shore

activity. Storage space is valuable aboard the tender, so a large inventory should not be carried. Also, the needs of the submarine customer must be met, so that an excess of orders should not pile up. The repair officer has decided to define a policy for the number of liners to be picked up each week—that this number is to be A times the net number of orders on hand and B times the net number of orders on hand at the first of the previous week. The problem is to determine the values of A and B which will yield best results. A flow graph of the system can be constructed, as in Figure 18.

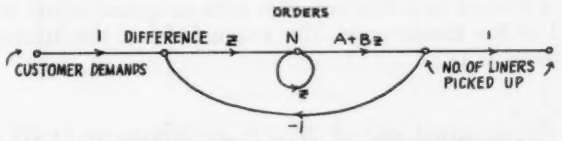


**Figure 18. A shipboard inventory control problem, where the supplier attempts to minimize either the number of back orders or the inventory with a simple weekly stock-ordering rule, A+Bz.**

The input is the total number of submarine orders for liners during the week. From this is subtracted the number of liners picked up at the beginning of the week. This difference, indexed in time by z, causes a change in the number of back orders, N, at the beginning of the next week. The self loop around N provides for the number of orders to remain constant from week to week if no net orders are received. A negative N indicates an accumulated inventory. N is the quantity of interest, and the transmission from customer demand to N is $\frac{z}{1-[z-z\,(A+Bz)]} = \frac{z}{1-z(1-A)+Bz^2}$

The response of N to a unit step, $\frac{1}{1-z}$, will be examined with several combinations of A and B to show their relative effects. A unit step simulates the effect of a sudden increase in orders on the system. In an actual situation, one good procedure might be to use as an input the data from a typical past interval of from 10 to 20 weeks and make a trial and error solution with various values of A and B, optimizing to some criterion such as the mean squared value of N over the run. Figure 19 shows step responses of N under various parameter combinations.

The unit step is arbitrarily selected as an input, but the various responses determined give some idea of the behavior of the actual system under varying inputs. For example, with A=0 and B=1, a very oscillatory fluctuation of the number of orders on hand results. Common sense indicates that the value of A should be at least unity, to ensure that the number of liners picked up at least equals the number of orders to be filled. Thus the combination A=2, B=$\frac{1}{2}$ appears to yield the best behavior of the responses shown, with a low ratio of net back orders to input demands after the initial transient decays.

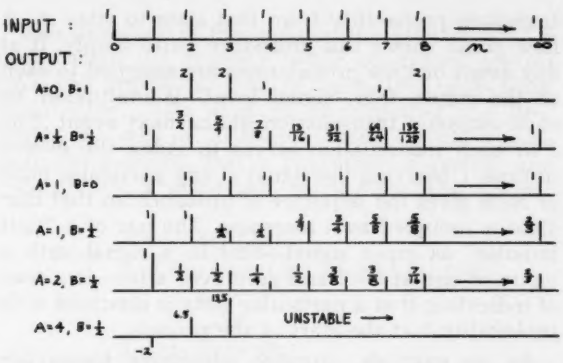


**Figure 19. Response of inventory N to a step input of customer demand, as shown in Figure 18. Various parameter changes indicate differences in steady-state response, varying oscillatory behavior, and instability.**

The last coefficient setting in Figure 19, A=4 and B=$\frac{1}{2}$, demonstrates unstable behavior, that is, N tends to increase without bound. This will occur when any root of the denominator equation occurs at an absolute value of z less than unity.

This example is typical of many decision-making processes, especially in business. Another very important and more practical application of the z-transform is in the design of digital computers for control of some physical process in real time.

## MARKOV PROCESSES

An advanced topic of probability theory which has been receiving increasing attention in recent years is that of Markov processes. A Markov process is defined by a discrete set of all possible "states" or conditions that a system can occupy, where the probability of a transition from one state to another is dependent only upon the two states involved and disregards entirely any past history of the system. For example, a gambler might choose to define his state as the number of dollars he is ahead or behind at the roulette table.

In general, a system will have a certain probability of being in each state after every transition. At any given time the sum of all these state probabilities is always one. The probability that a system is in a particular state A at times n is found from the sum of the individual probabilities of all the ways the State A can occur. Each individual probability is then the product of the occupancy probability of any particular state at time n−1 and the

transition probability from that state to state A. A flow graph shows this procedure quite simply. If at any event or time probabilities are assigned to each of the states, this "signal level" is multiplied by each outgoing transmission at the next event. The z in each transmission serves to index the events in time. Observing the signal at any particular node or state gives the sequence of probabilities that that state is occupied as n increases. The use of a "unit impulse" as input signal—that is, a signal with a value of one at n=0 and zero ever after—is a way of indicating that a particular state is occupied with probability 1 at the start of the process.

As an example, suppose successive tosses are made of an unbiased coin. Two states or results are defined—Head or Tails. Obviously, if the system (the coin and coin-tossing mechanism) is in one state, say Heads, there is a probability of ½ that the next state will be the same one, and ½ that it will be different. A flow graph of this system is shown in Figure 20. Let us assume that a n=0, the system is known to be in state Heads, with a probability of 1. After the next toss, there will be a probability of ½ that the system will be in either state and this probability will hold for all successive tosses.

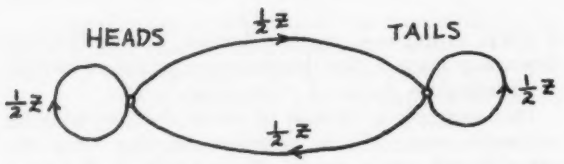


**Figure 20. Flow graph of simple Markov process, a coin-tossing experiment.**

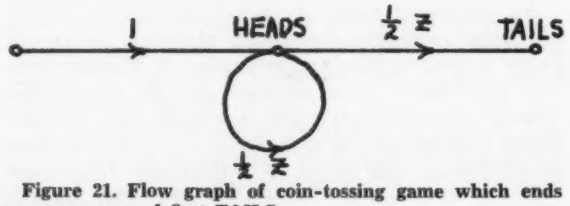


**Figure 21. Flow graph of coin-tossing game which ends on occurrence of first TAILS.**

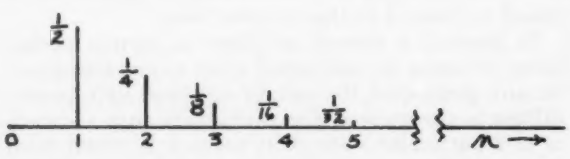


**Figure 22. Output of system of Figure 21, which is probability of the game ending on the nth toss.**

Tracing the signal flow, a 1 exists at state Heads at n=0. At n=1, State Tails receives a signal of ½ from Heads and 0 from itself, and Heads receives ½ from itself and 0 from State Tails. At n=2 each state receives $\frac{1}{2} \cdot \frac{1}{2} = \frac{1}{4}$ from itself and from the opposite state.

Suppose the system or game is redefined so as to stop when the first tails is obtained, and the probability of this occurring on the nth toss is desired, as shown in Figure 21. In other words, the signal which leaves the Heads node toward the Tails node is wanted as a function of n with an initial signal of 1 at the Heads node. The z-transform of this transmission is

$$\frac{\frac{1}{2}z}{1-\frac{1}{2}z} = \frac{1}{2}z + \frac{1}{4}z^2 + \frac{1}{8}z^3 + \frac{1}{16}z^4 + \ldots$$

which is shown in Figure 22 and is the desired probability distribution (note that the sum of all probabilities is unity).

The two simple examples above have illustrated the central features of the Markov process. The coin-toss is completely determined by two states, Heads or Tails. The probability that the next state is Heads, for example, given that the present state is Tails, is a constant and only depends on the present state. The flow graph has provided a picture of the relationships involved, and the z-transform has enabled a probability distribution to be expressed in closed form, as for example, $\frac{\frac{1}{2}z}{1-\frac{1}{2}z}$. The z-transform technique is valuable for other reasons. When a discrete probability distribution is used for some practical purpose, two characteristics are usually the most significant. First is the mean, average, or expected value of the random variable, defined by $\bar{n} = \sum_{n=0}^{\infty} n\,P(n)$. Next, the variance, $\sigma^2$, which gives a measure of how close the distribution is grouped to its mean, is defined by $\sigma^2 = \sum_{n=0}^{\infty} (n-\bar{n})^2 P(n)$.

Since the z-transform of a discrete probability distribution is $P(z) = P_0 + P_1 z + P_2 z^2 + P_3 z^3 \ldots$, it is obvious that setting z=1 in P(z) should yield P(1)=1, since the sum of all probabilities is unity. Similarly, differentiating P(z) with respect to z yields

$$P'(z) = P_1 + 2P_2 z + 3P_3 z^2 \ldots$$

equal to $\bar{n}$. In a similar fashion $\sigma^2$ can be shown to equal $P''(z)|_{z=1} + \bar{n} - (\bar{n})^2$. These results are summarized in Table II.

TABLE II. *Statistical parameters obtained from z-transform of probability distribution*

| Quantity | Symbol | Transform Relation |
|---|---|---|
| Expected value | $\bar{n}$ | $\frac{d}{dz}[P(z)]\|_{z=1}$ |
| Variance | $\sigma^2$ | $\frac{d^2}{dz^2}[P(z)]\|_{z=1}+\bar{n}-(n)^2$ |

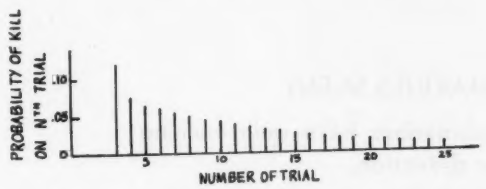


**Figure 24a. Probability of ASW exercise ending on nth trial.**

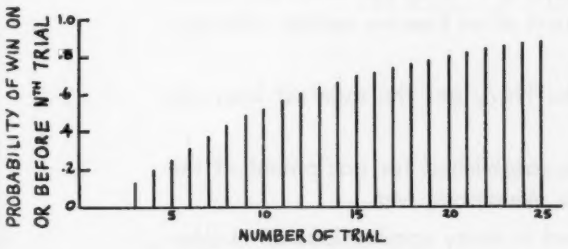


**Figure 24b. Cumulative probability of exercise ending on or before nth trial.**

A hypothetical example will illustrate these ideas:

A destroyer is engaging in an ASW training exercise with a submarine on Friday afternoon. The rules for the operation specify that three successful attacks must be made in succession by the destroyer before the exercise can be terminated. Anxious to get home at the end of the week, the destroyer captain desires to estimate the average number of runs required and also the accuracy of this average. He estimates that the probability of a successful attack after one or more failures, is 0.4. Realizing that the humans involved in the operation will improve their performance as a possibility of a "win" of the game seems closer, he assigns a .50 probability for success immediately after one previous success, and a .60 probability after two consecutive successes. The flow graph for this system is shown in Figure 23.

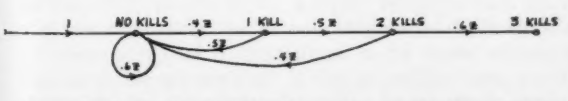


**Figure 23. Hypothetical ASW exercise as Markov process, where three successive "kills" on a submarine are required to win.**

The transform of the signal at the THREE KILLS node, when the system's initial conditions are set by a unit impulse at n=0, is the desired probability distribution. Note that in constructing the flow graph, the sum of all transmissions leaving a node is unity, meaning that a transition is certain and "probability is preserved, solving the flow graph,"

$$P(z)=\frac{(.4z)\ (.5z)\ (.6z)}{1-[.6z+(.4z)\ (.5z)+(.4z)\ (.5z)\ (.4z)]}$$

$$=\frac{.12z^3}{1-.6z-.2z^2-.08z^3}$$

$P(1)$ is seen to equal 1. $P'(1)$ can be shown to equal 13.33, and $P''(1)$ is found to be 289. Hence, from Table II, $\bar{n}$ or the mean number of runs on the submarine is equal to 13.33 and $\sigma^2=289+13.3-(13.3)^2$ or 124.73. The standard deviation, $\sigma$, is the expected rms deviation of the number of trials about the mean, and equals 11.18. $P(n)$ is determined from the transform and is shown in Figure 24. Also shown is its cumulative sum, which gives the probability that the exercise will be over on or before the nth trial. Thus, the exercise has a 50 per cent probability of ending by the 10th trial, and an 80 per cent probability of ending by the 20th trial.

## CONCLUSIONS

Many of the most interesting engineering problems are concerned with dynamic behavior, with quantities which change in some manner with time. A large majority of these problems are essentially linear over a certain range and thus the techniques of linear systems analysis provide a useful and unified method of attack. The signal flow graph has been shown to be of use in seeing the complex inter-relationships which may exist between variables in a linear system and for actually solving problems of response to a given excitation. Military and business operational "systems," although not existing as hardware, can often be approximated and analyzed by a linear model, where again the flow graph improves the insight and minimizes the computational labor. It is expected that in future years this concise analysis tool will become universally used in all branches of engineering involving dynamic processes.

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## QUIET BEARINGS KEEP SUBMARINES SILENT

Electronics will help make sure U. S. submarines have quiet-running bearings—a must to avoid unfriendly sonar detection.

Researchers at SKF Industries, Inc., Phila., Pa., have come up with an electronic check method for noise measuring devices. The system will be used by SKF to uniformly set test equipment which examines the noise-producing vibration levels on the products of six bearing makers who supply the Navy.

Critical Need—The aim: Helping the Navy get the quietest bearings made in the U. S.

The same calibration system will be established for equipment at the Navy's Engineering Experiment Station, Annapolis, Md.

"Quiet-running rolling bearings—used in many applications on nuclear powered submarines—are a critical need if American submarines are to escape unfriendly sonar detection," says Thomas W. Morrison, SKF director of engineering and research, announcing the contract.

Formerly SKF used a "master" bearing to check the test equipment. The test gear determines bearing vibration in much the same way a phonograph pick-up arm obtains sound from a record's grooves. However, the master bearing was subject to normal wear and deterioration. This sometimes caused unreliable calibration, SKF says.

Now, SKF researchers have developed the electronic check method which eliminates the master bearing. It also sets up a uniform system for electrical and mechanical calibration of test equipment. And it ends the need for lot acceptance testing at a government laboratory.

"THE MOTOR SHIP"

# *THE FREE PISTON-ENGINED SHELTER-DECKER* REMBRANDT

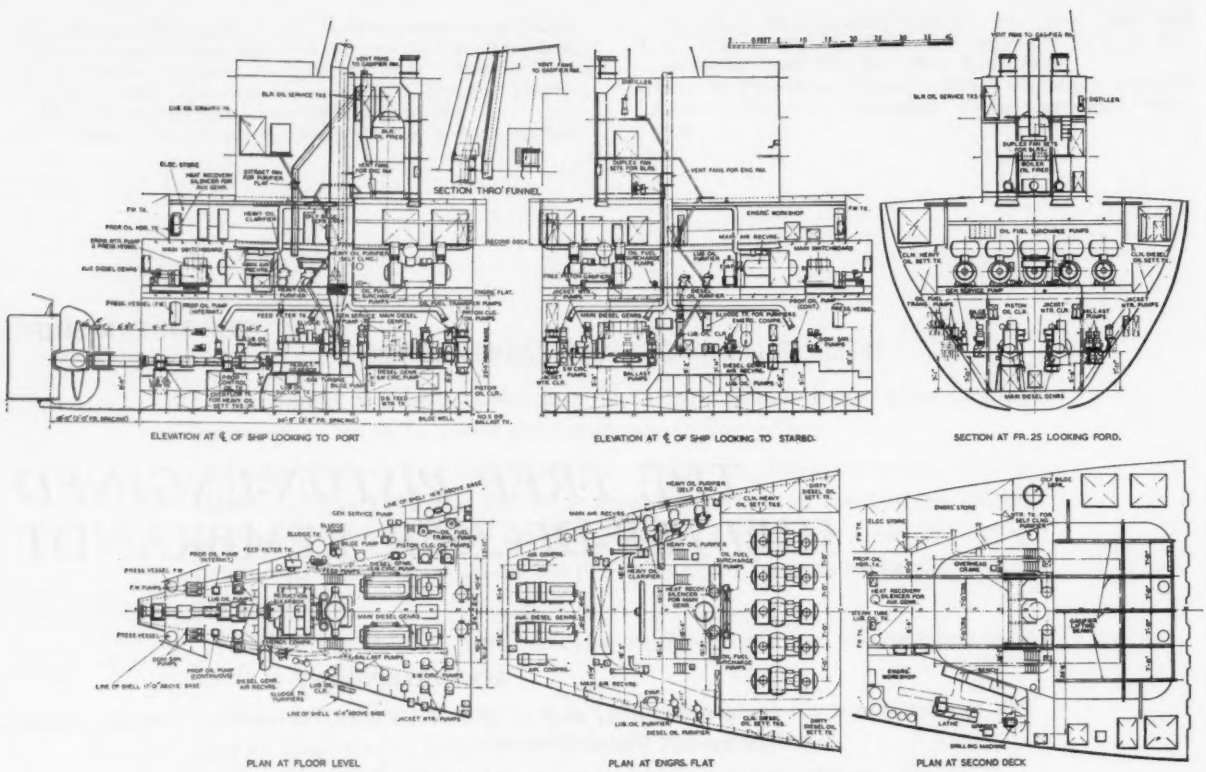
**ACKNOWLEDGMENT**

*This article, by the staff of "The Motor Ship," is reprinted from the August 1960 issue of that publication.*

THE HIGHEST-POWERED newly built free-piston-engined general cargo vessel *Rembrandt*—built and engined by Smith's Dock Company, Ltd., of South Bank, Middlesbrough, for the Bolton Steam Shipping Co., Ltd., of London—was open to inspection last summer to a large gathering of marine superintendents and the technical Press, and a short demonstration trial run was held so that an appraisal could be made of the main machinery.

Designed from the outset to take advantage of the characteristics of free-piston machinery, the *Rembrandt* is the first British-built vessel of this type to be fitted with a controllable-pitch propeller. This is of the Kamewa design and was constructed by the Stone Marine Engineering Co., Ltd. The main advantage of such a propeller for gas turbine-propelled ships is the elimination of astern blading in the turbine with a corresponding reduction in windage losses. It is expected that *Rembrandt's* turbine will prove to be a more efficient unit than one incorporating an astern stage and will enable economies in fuel consumption to be made. Against this must be set the cost of the propeller, and it will obviously be a considerable time before fuel economies pay for this item. As operation in the St. Lawrence Seaway may be called for, the precise maneuvering necessary will be facilitated by the use of the controllable-pitch propeller, which will probably prove to be of considerable advantage. On trials in the ballast condition and with the gasifiers burning Diesel fuel, a specific fuel consumption of 0.428 lb/shp-hr was obtained with the turbine developing 3,870 shp, or 96.75 per cent of the maximum continuous output of 4,000 shp.

For the complete engine-room installation a weight of 420 tons has been given; this includes the main and auxiliary machinery, pipes and fittings, oil and water systems, sterngear, tanks, ladders, floors and gratings, funnel and vents, and all spares and stores.


SECTION THRO' FUNNEL
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SECTION AT FR. 25 LOOKING FORD.
PLAN AT FLOOR LEVEL
PLAN AT ENGRS. FLAT
PLAN AT SECOND DECK

**Figure 1. Engine Room Plans of the Fire-Piston Gas Turbine-Propelled M.S. *Rembrandt***

### MACHINERY DESCRIPTION

By specifying free-piston gas-turbine machinery from the outset the owners of the *Rembrandt* claim to have saved something in the region of 200 tons deadweight over an installation of similar output from the more conventional prime movers, while the compactness of the installation has allowed six frame spaces to be saved with a corresponding increase in the carrying capacity of the vessel. A breakdown of the main machinery weights is as follows:—

| | tons |
|---|---|
| 5 GS.34 type gasifiers with recirculation | 41.0 |
| 1 Gas turbine with lagging and cover | 6.0 |
| 1 Double-reduction gearbox with thrust block | 30.15 |
| 1 Set gas piping between gasifiers and turbine complete with lagging | 3.5 |
| 1 Control console with instruments | 1.15 |
| 1 Set blow-off piping complete with lagging | 1.3 |
| Total weight of main machinery | 83.1 |

Although figures published in *The Motor Ship* for January, 1960, suggest that the almost universal GS.34 gasifier is a unit of an increasing degree of reliability, *Rembrandt* installation includes five GS.34 gasifiers, only four of which will be used for normal full-power operation with one unit as a stand-by for use during normal injector overhauling, etc. This should enable *Rembrandt* to eliminate out-of-service delays and maintain an excellent earning capacity throughout the life of the vessel. Multi-engined ships and proposals for this type of vessel have for long been regarded as attractive propositions from the point of view of earning power, but it is only with the advent of free-piston gas-turbine plant that the multi-engined installation becomes an attractive proposition in terms of first cost. The GS.34 gasifier, with a weight of only about eight tons, is a simple and comparatively inexpensive unit and may be positioned in the engine-room at almost any point available, provided a fairly easy gas-pipe run is allowed for, and thus probably comes nearer to the ideal of flexibility of installation than any other type of machine. Naturally, with the use of a single turbine a multi-free-piston installation cannot be regarded as a true multi-engined installation, but considerable experience with land and marine gas turbines used in conjunction with GS.34 gasifiers has led to the claim that the moderate temperatures and pressures involved allow the actual prime mover to attain almost 100 per cent reliability.

The gasifiers in *Rembrandt* are of standard design, built by Smith's Dock Co., Ltd., under licence from Alan Muntz and Co.; these machines incorporate design improvements resulting from recent research and the experience gained from the *Goodwood* conversion. In order to obtain a low fuel con-

sumption and to avoid wastage of gas by blowing-off in this condition, the machines are fitted with recirculation valves which enable the gasifiers to match the turbine swallowing capacity over the whole pressure range. When idling with this device the gasifiers develop only 20 hp each, thus assisting in precise maneuvering in restricted waters.

### GASIFIER INTAKE ARRANGEMENTS

It must be admitted that one of the operating problems with free-piston machinery is the low-frequency pulsating effect from the gasifiers which, unless careful attention is paid to the air intake arrangements, can be extremely heavy. Various air intake arrangements have been described in *The Motor Ship* from time to time, the most recent example being that of *Geestland* (*The Motor Ship*, May, 1960), where the gasifiers draw air from a long intake with their air suction at the top of the funnel. Although this would seem to be an ideal arrangement, the *Rembrandt* installation is much simpler: the gasifiers in this case are fitted with short air intakes of Smith's Dock design which incorporate a Woods Aerofoil free-running fan with the object of evening-out the airflow. This intake design has been developed from *Goodwood* and is said to ensure a positive pressure in the inlet casings when the suction valve closes, thus assisting the compressor charging and easing the engine loading for any given gas pressure. Unfortunately, it would seem that the theoretically perfect intake design is also the one with the heaviest pulsation effect and *Rembrandt's* gasifiers have, therefore, been arranged to run in phase with the object of minimizing intake and gas main pulsations and reducing the overall noise level in the audible frequency range.

To confirm the results of test-bed experiments in sea-service, different combinations of liners and piston rings are fitted in the five gasifiers. One gasifier has standard cast-iron rings and liners, two have S.G. iron piston rings with special cast-iron liners, one has cast-iron rings and a chrome-plated liner, and, finally, one has chrome-plated S.G. iron rings and a special cast-iron liner. Further refinements to the gasifier design include a new type of stabilizer for rapid load changing and a new Muntz sight glass for the Martin 27-point lubricator. The turbine and

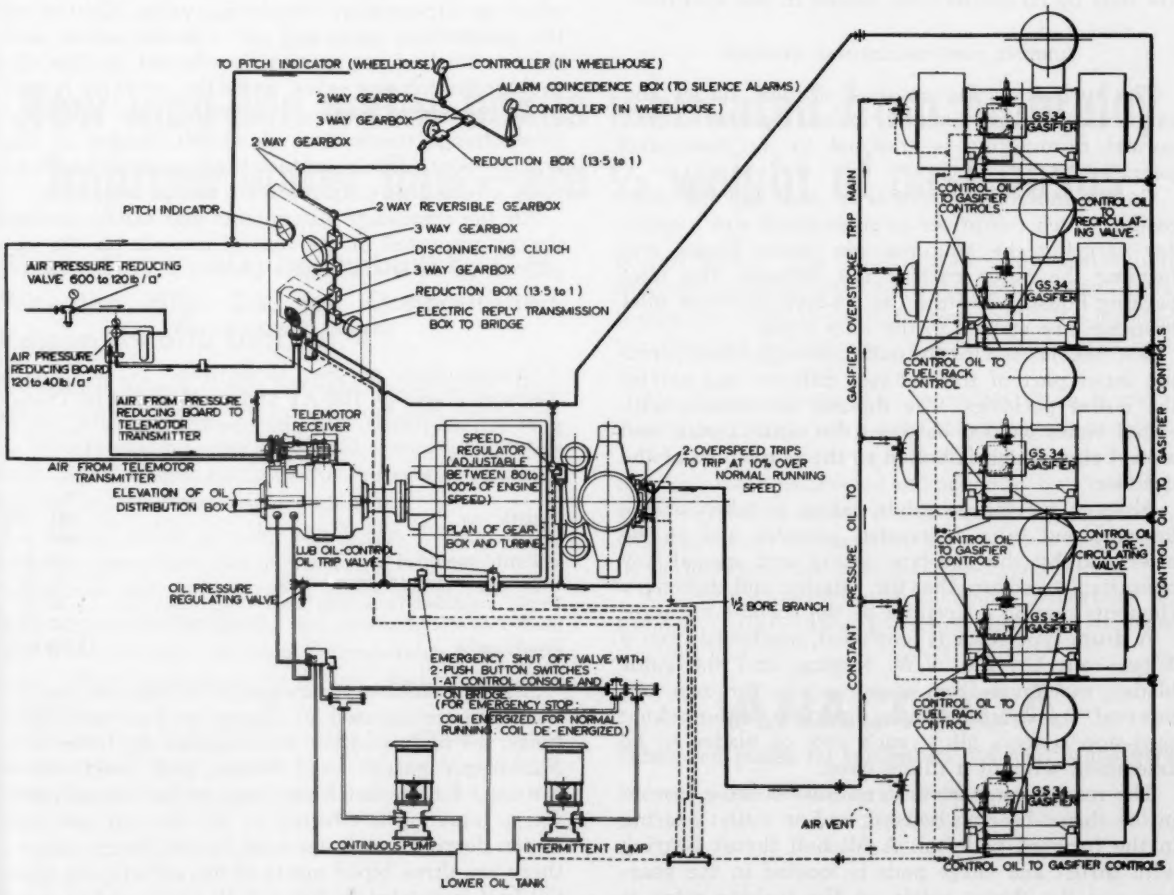
TO PITCH INDICATOR (WHEELHOUSE)
CONTROLLER (IN WHEELHOUSE)
ALARM COINCEDENCE BOX (TO SILENCE ALARMS)
2 WAY GEARBOX
3 WAY GEARBOX
CONTROLLER (IN WHEELHOUSE)
2 WAY GEARBOX
REDUCTION BOX (13·5 to 1)
PITCH INDICATOR
2 WAY REVERSIBLE GEARBOX
3 WAY GEARBOX
DISCONNECTING CLUTCH
3 WAY GEARBOX
REDUCTION BOX (13·5 to 1)
ELECTRIC REPLY TRANSMISSION BOX TO BRIDGE
AIR PRESSURE REDUCING VALVE 600 to 120 lb / □"
AIR PRESSURE REDUCING BOARD 120 to 40 lb / □"
AIR FROM PRESSURE REDUCING BOARD TO TELEMOTOR TRANSMITTER
TELEMOTOR RECEIVER
AIR FROM TELEMOTOR TRANSMITTER
ELEVATION OF OIL DISTRIBUTION BOX
SPEED REGULATOR (ADJUSTABLE BETWEEN 80 to 100% OF ENGINE SPEED)
PLAN OF GEAR-BOX AND TURBINE
2 OVERSPEED TRIPS TO TRIP AT 10% OVER NORMAL RUNNING SPEED
LUB OIL-CONTROL OIL TRIP VALVE
OIL PRESSURE REGULATING VALVE
½ BORE BRANCH
EMERGENCY SHUT OFF VALVE WITH 2-PUSH BUTTON SWITCHES 1-AT CONTROL CONSOLE AND 1-ON BRIDGE (FOR EMERGENCY STOP: COIL ENERGIZED FOR NORMAL RUNNING. COIL DE-ENERGIZED)
CONTINUOUS PUMP
INTERMITTENT PUMP
LOWER OIL TANK
AIR VENT
CONSTANT PRESSURE OIL TO GASIFIER OVERSTROKE TRIP MAIN
CONTROL OIL TO GASIFIER CONTROLS
GS 34 GASIFIER
CONTROL OIL TO GASIFIER CONTROLS
CONTROL OIL TO RECIRCULATING VALVE
CONTROL OIL TO FUEL RACK CONTROL
CONTROL OIL TO GASIFIER CONTROLS
CONTROL OIL TO RE-CIRCULATING VALVE
CONTROL OIL TO FUEL RACK CONTROL
CONTROL OIL TO GASIFIER CONTROLS

**Figure 2. Diagrammatic layout of the gasifier control system.**

reduction gearing were constructed by The British Thomson-Houston Co., Ltd., of Rugby. Details of the gas turbine are as follows:—

| Type | Six-stage reaction, uni-directional Rating | | |
|---|---|---|---|
| | 1 hour Overload | Max. | con-tinuous |
| Number of gasifiers | 4 | 4 | 3 |
| Delivery pressure, psig | 46.7 | 43.1 | 26.4 |
| Delivery temperature, °C | 482 | 462 | 365 |
| Total mass flow, lb/sec | 34.7 | 33.0 | 24.3 |
| Output at turbine coupling, hp | 4,600 | 4,110 | 2,000 |
| Turbine speed, rpm | 7,050 | 6,800 | 5,350 |

It will be seen from the table and the continuous maximum figures for the gasifiers that a pressure drop of 1 psi is allowed in the gas piping and a gearing efficiency of 97.5 per cent is required to achieve the designed shaft horse-power output and specific fuel consumption. It is possible to develop 2,000 shp with three gasifiers only, and in this condition the limit is imposed by the maximum pressure attainable by the three gasifiers working on the fixed area of the turbine. The gas delivery pressure from the gasifiers is then 26.4 psig and the three gasifiers are thus by no means fully loaded in this condition.

### TURBINE CONSTRUCTIONAL DETAILS

The turbine casing consists of inlet, outlet and exhaust casings permanently bolted together so that normal dismantling is confined to the horizontal joints.

Carbon-molybdenum steel is used for the inlet casing, which comprises an inlet scroll and a cylinder carrying the stainless-iron stator blades and forming the outer part of the diffuser. The inlet packing housing and the two 14-inch diameter inlet branches are welded to the inlet scroll.

Cast steel is used for the outlet casings, which forms the inner part of the exhaust diffuser and carries the outlet packings. The diffuser terminates with radial vanes welded between the outlet casing and a steel ring which is bolted to the outer part of the diffuser.

Support for the complete casing is taken at the forward end by a fabricated pedestal and at the after end by the gearbox casing and special key mountings to ensure that the rotating and stationary elements remain concentric as the turbine expands.

A drum-type rotor is employed, machined from a 3 per cent Cr. Mo. V.W. forging, and the rotor blades, machined from stainless-iron forgings, are inserted in circumferential grooves. Interlocking split-stop spacers allow each row of blades to be assembled without a filling gate.

The rotor is supported on an inlet bearing carried in the thrust-bearing housing and an outlet bearing in the forward pedestal. A Michell thrust bearing with thrust and surge pads is located in the gearbox and the thrust collar on the turbine rotor is nitrided and ground. An emergency thrust bearing in the form of two squealer rings is provided to locate the turbine rotor in the case of failure of the main thrust bearing.

As stated, the reduction gearing is also of B.T.H. manufacture. This is of the locked-train double-reduction type housed in a fabricated-steel casing. Drive is taken direct from the turbine to the quill drive of the high-speed pinion assembly, which meshes with two single-helical gearwheels to make up the first reduction. An over-drive claw coupling is provided in the high-speed pinion assembly to transmit load direct to the pinion, instead of through the quill drive, in cases of excessive load. Double-disc thrust bearings of the Michell type are mounted on the flexible layshafts; these bearings also locate the axial position of the wheels in the gear case.

### CONTROL SYSTEM

A diagrammatic arrangement showing the layout of the main control system is shown in Figure 2. The single handwheel shown on the control console turns a layshaft carrying two cams, one of which operates an oil-pressure regulating valve and the other an air-pressure regulating valve. Control of the gasifier fuel racks and recirculation valves, and thus control of gas output, is effected by the oil-pressure regulating valve, while the air valve is part of a telemotor system controlling the propeller pitch-change mechanism. A clutch located at the engine-room console enables these control functions to be effected directly from the bridge telegraph.

All the necessary instruments and safety devices are incorporated in the control console for the operation of the main engine plant.

### GENERAL DESCRIPTION

Construction of the *Rembrandt* is to Loyd's Register class ✠ 100 A1 and to Ministry of Transport requirements, and she has the following main particulars:—

| | ft. | in. |
|---|---|---|
| Length o.a. | 491 | 9⅜ |
| Length b.p. | 460 | 0 |
| Breadth, moulded | 63 | 0 |
| Depth, moulded to upper deck | 41 | 9 |
| Depth, moulded to second deck | 32 | 6 |
| Draft | 27 | 8 |
| Deadweight | 12,940 tons | |

All the machinery, navigation bridge and accommodation are situated aft. There are five main cargo holds, the main weather deck hatches are fitted with MacGregor patent steel covers, and wood covers are used for the hatch openings in the second deck. Cargo handling is effected by six five-ton and four 10-ton derricks, each operated by an electric winch; there are three bipod masts of the self-staying type. Oil fuel is carried in No. 4 D.B. tanks and in wing tanks between Nos. 3 and 4 holds. Water ballast is

carried in the remaining double-bottom tanks, in wing tanks between Nos. 1 and 2 and 2 and 3 holds, and in the forward and aft peaks.

The *Rembrandt* is a general-purpose cargo vessel intended for the trampship trades and the enterprise of her owners in specifying machinery of such an advanced type is to be commended. No doubt further developments with free-piston machinery will lead to reductions in fuel consumption and to outputs suited to the larger vessels, but at the present time, after only a comparatively short period of development, this type of plant is now the subject of serious consideration for a number of classes of ships. It would seem that some comparatively simple arrangements could be made to improve the overall thermal efficiency of free-piston-engined plant, i.e., the turbine exhaust could be used in an exhaust-gas-fired boiler as in the re-engined *Morar* (*The Motor Ship*, July, 1960) and a small auxiliary turbine could be driven by excess air drawn from the engine case of one or more gas generators; this turbine could be used to drive cooling-water pumps or other essential services. However, it was thought that in the case of *Rembrandt* sufficient new-type machinery had been installed at the outset. When this type of installation has proven reliable it seems probable that such methods of increasing efficiency will be more closely studied.


# New long-life water boxes fabricated from Ambraloy improve water flow—are ⅓ weight of cast boxes

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The boxes – eight in all to serve a 198,000-sq.-ft. twin-shell condenser – were fabricated from hot-rolled Ambraloy-930 plate, ⅜" gage throughout. At main seams, segments were prebeveled and joined by butt welding. Fillet welds were used to attach inlet nozzles, manholes, vents, and steel stiffener ribs. Most of the welding was by the inert-gas, consumable-electrode process.

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FENDALL MARBURY, JR.

# THE AIRSCREW FOR SHIP PROPULSION: ITS COMMERCIAL ASPECT

**THE AUTHOR**

*is a graduate of the Webb Institute of Naval Architecture (BS, 1959), the Massachusetts Institute of Technology (SM, 1955) and the Oak Ridge School of Reactor Technology. He served three years active duty in the Navy as an engineering duty officer, two in the Puget Sound Naval Shipyard and one in the Ships Supply Depot, NSC, Norfolk, Va. Formerly head of the Shielding and Structural Section, Nuclear Power Department, The Ingalls Shipbuilding Corporation, he is now a scientific analyst with the Operations Evaluation Group, Office of the Chief of Naval Operations.*

## INTRODUCTION

U. S. NAVY TESTS of airscrew propulsion on the Liberty ship *John L. Sullivan* (YAG-37), figure 1, raise the question as to whether or not such propulsion of heavy ships has or can have any commercial advantage over conventional propulsion by water screw.

Airscrews have been used for some years to propel small light boats in debris-filled shallow water, especially swamps. The Navy had developed a requirement to maneuver large ships in shallow debris-filled water; so turned to the airscrew. The *John L. Sullivan* was fitted with four turboprop aircraft engines mounted on rotatable 40mm gun mounts, two forward and two aft. The engines were run at 3,000 hp each, or a total of 12,000 hp, during the tests.

As to results, the Navy's YAG 37 Information Release, dated 4 September 1957, says, "The test results show the ship to be highly maneuverable with this propulsion system, actually being better than a conventional power plant at lower speeds or at a standstill. Approaching piers or mooring buoys the capability to apply propulsive force in any direction was a substantial improvement and entirely eliminated the need for tug boat assistance." This is a clear commercial advantage.

However, commercial ardor cools when we read the next sentence, "Speed attained under full displacement was approximately seven (7) knots.", and reflect that seven knots on 12,000 horsepower compares badly with the normal Liberty's performance of ten knots on about 2,000 horsepower.

Why should the YAG 37 take such a beating in propulsive efficiency just by changing its propulsive medium from water to air? The answer is, of course,

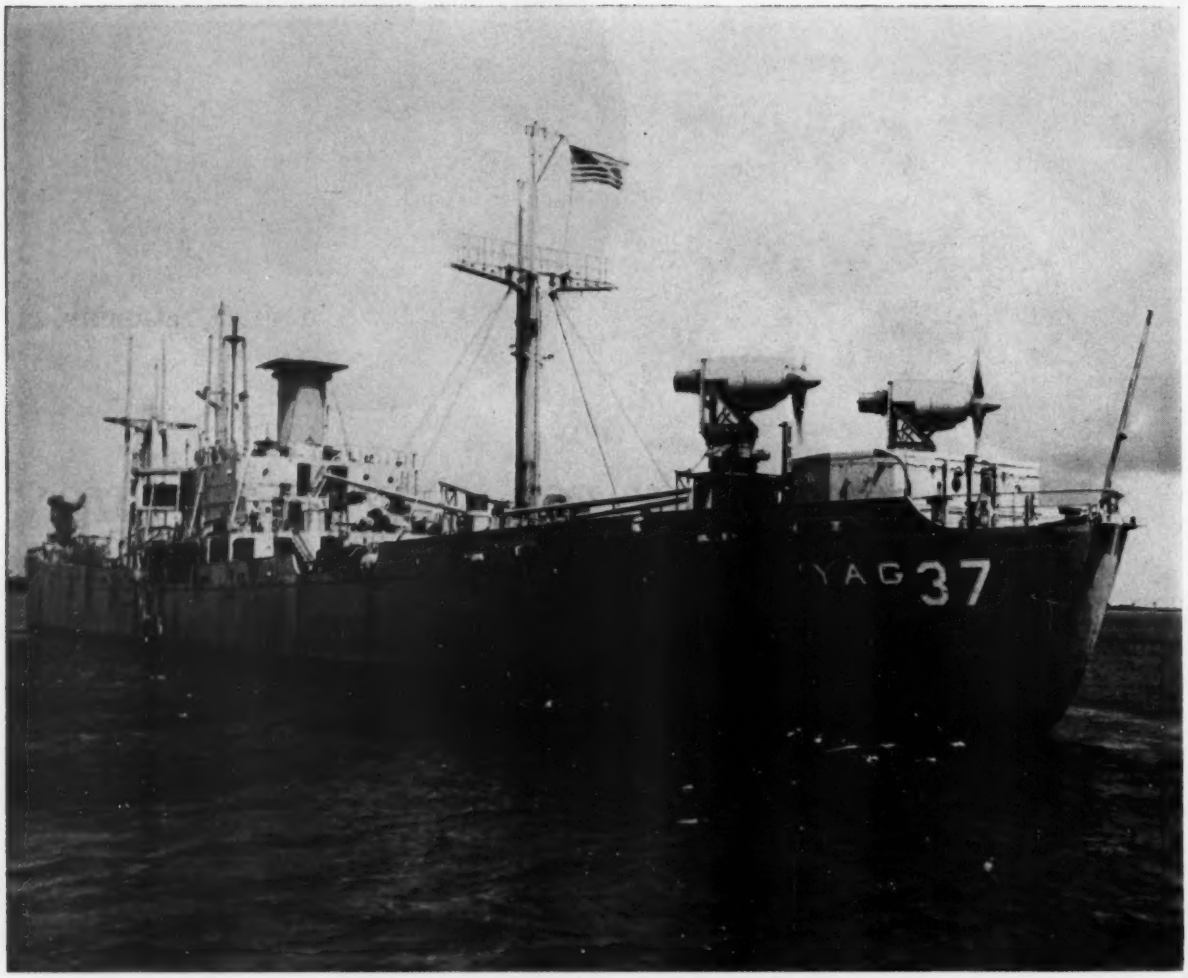



**Figure 1. Liberty ship JOHN L. SULLIVAN (YAG-37)**

that something else was changed also, and that it was important. The next sentence of the Information Release gives a clue: "Additional speed could be achieved by use of propellers designed for this type of operation, but the performance with propellers designed for aircraft use was considered adequate to prove the effectiveness of the system." The purpose of this article is to go more thoroughly into the matter of what a propeller "designed for this type of operation" would be like and into a surprising consequence of its use.

### LIMITS OF AIRSCREW PROPULSIVE EFFICIENCY

The most important defect of the YAG 37's propellers was their small size. To bring this out, let us evaluate its propulsion system by applying the simple momentum theory of propeller action. First enuciated by W.J.M. Rankine in 1865, this theory explains the connection between thrust and the change of momentum of the stream of water passing through the propeller disk. The propeller is visualized as an "actuater disk" or area transverse to the flow with a pressure difference across it produced by some means or other. Since the pressure difference and resulting increase in velocity of the water stream are assumed to be produced without energy loss, the momentum theory efficiency of a propeller is the highest efficiency that propeller can possibly have, and it is always less than 100 percent. Though developed with ships in mind, the theory applies equally well to air and water, to aircraft as well as watercraft.

It should be emphasized that the simple momentum theory gives no details of a propeller's design, as the only propeller dimension which enters it is the diameter. The most desirable number of blades, pitch, rotative speed, blade width, airfoil sections, and so on for a given propeller must be determined

by other means, chiefly by model tests and by more sophisticated theories. What it does give is the upper limit of efficiency (the "ideal" efficiency) for a propeller of a given size generating a given thrust at a given speed of advance through a fluid of given density. Hence, this simple theory will indicate how big an airscrew must be to propel a Liberty ship at a given speed with a specified efficiency.

For the evaluation, we shall need the following results of the simple theory:

The formula for thrust:

$$T = Q\,c_a$$

where $Q = A\left(v_e + \frac{c_a}{2}\right)$

The formula for ideal (momentum theory) efficiency:

$$e_i = \frac{1}{1+\frac{1}{2}\,(c_a/v_e)} = \frac{1}{1+s/2}$$

where $s = \frac{c_a}{v_e}$

where: T, propeller thrust in pounds.
Q is volumetric flow rate of fluid through the propeller disk, $ft^3/sec$.
$c_a$ is the velocity increase of the fluid stream causd by the propeller, ft/sec.
A is the propeller disk area, transverse to flow, $ft^2$
$v_e$ is the velocity of the water stream approaching the propeller disk, ft/sec.

Going straight to the question of efficiency, we see that it depends only on the ratio $c_a/v_e$, which is usually called the slip. For a typical ship or airplane, the slip might be 0.1 or 0.2, which corresponds to an ideal efficiency of 95 or 91 percent respectively. (Airplanes tend to have lower slips than ships, but both are much closer to zero than to one.)

By contrast, the corresponding figures for the YAG-37, as nearly as the author can estimate them from the scanty published data, are for slip, 12.7 and for ideal efficiency about 14 percent. The propulsive efficiencies actually obtained under these conditions are 75 to 80 percent for a normal ship and about 4 percent for the YAG 37.

Hence the YAG-37's low efficiency is no accident, but a consequence of the high slip at which it operates. Air comes whistling out of its propellers about 100 miles per hour faster than it went in, and all this velocity goes to waste. Let us now consult the simple momentum theory formulae to find how the YAG-37's efficiency can be raised.

First, the slip must be low. Instead of 12 or 13, it must have a value down around 0.1 or 0.2, within the bounds of normal ship and airplane practice. This will give an ideal efficiency of 90 percent to 95 percent, assuring an actual efficiency in the range 60 percent to 80 percent. Also, the thrust must be the same as before, to obtain the same speed.

According to the momentum theory, the thrust obtained at a given slip is proportional to the mass flow rate, Q, through the propeller. The mass density of sea water is about 800 times that of air at sea level. Therefore, to enable it to handle the large volume of air required, an airscrew must be much larger than a water screw to produce the same thrust at equal efficiency.

Assuming a speed of 10 knots and a slip of 0.2 (ideal efficiency of 91 percent), the simple momentum theory gives a propeller diameter of 660 feet, for a Liberty ship. If two screws were used, each would be 465 feet in diameter, and all are supposed to go on a 400 foot ship! This is much too big, of course; so the question arises of how big an airscrew a ship can reasonably be expected to carry.

### THE AIRSCREW AS A SAIL

At this point, new facts must be introduced. First, airscrews and windmills are aerodynamically very similar. In fact, their only difference is this: that to develop thrust in a given direction, the pitch of one is in the opposite direction to the pitch of the other. See Figure 2. Their corresponding air flow directions are opposite, also. Thus, to convert an airscrew into a windmill, one has only to reverse its pitch. Its direction of rotation will still be correct, and its blades will be cambered on the right side.

Second, when a windmill is operating in the zero-torque or no-load condition, with no power being taken from the shaft, it nevertheless develops a thrust or reaction to the wind, which can be sizeable. For example, a strong braking influence is felt when an airplane's propeller is allowed to windmill. By momentum theory, this thrust is proportional to the size of the windmill's swept area and the amount by which the wind passing through it is slowed down. In actual windmills, high thrust is obtained by making pitch low and allowing high rotative speeds.

One practical use of the no-load thrust of a windmill was de la Cierva's autogiro of the nineteen twenties and early thirties, an aircraft whose principal support was an unpowered rotor, or windmill, set with its plane of rotation at an angle of attack of the passing air. Thus, the autogiro's rotor had the same position and function as the wing of a normal airplane and operated in the same aeordynamic condition as the sail of a ship going to windward.

Hence it is possible to use a no-load windmill in place of sails to drive a ship. This has been done, notably by Mr. E. Burke Wilford of Merion, Pennsylvania, who holds U. S. patents numbers 2,152,984 and 2,152,983 on this application of windmills dated shortly after the advent of the autogiro. Mr. Wilford installed two and three-bladed windmills on a star class hull and reported them to be quite ef-

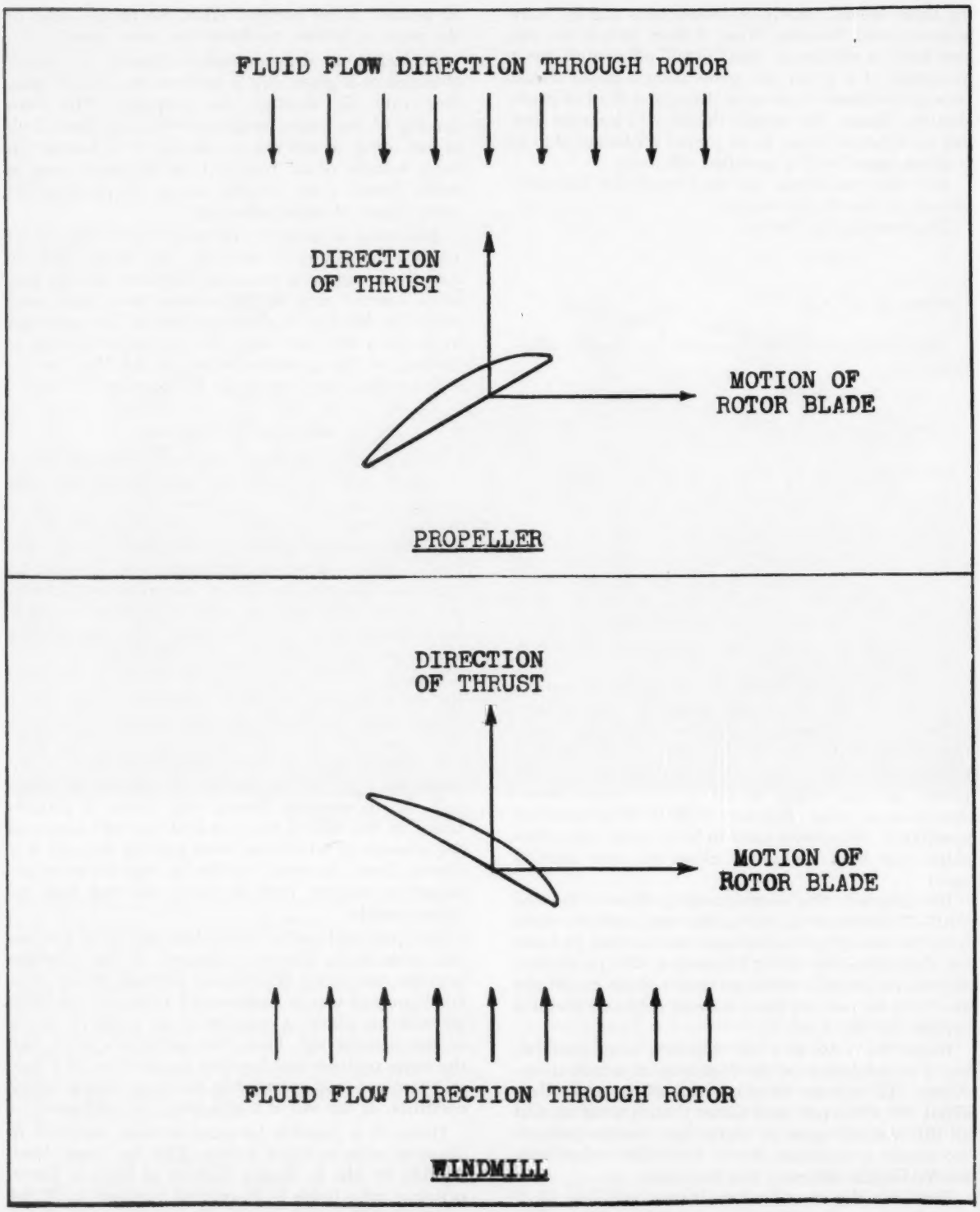



**Figure 2. Thrust, flow and blade motion directions for propellers and windmills.**

fective when reaching but inferior to yacht sails when going to windward. The author has installed windmills on both a model and a fourteen foot skiff, which also behaved in this manner.

Mr. Wilford's windmill was a large affair, of diameter slightly less than the length of his boat, figure 3. It was mounted at the head of a stayed mast, with its plane of rotation almost vertical. Its plane of rotation could be set in any of the positions with respect to the boat's centerline that a square sail can be set. In fact, the way to sail this boat was to set the plane of rotation of its rotor (by rotating the mast) as one would set a square sail. The boat also had the square rigger's seagoing advantage, freedom from jibes.

To convert the wind-driven device described above into an airscrew, one has only to provide a means for reversing the pitch of the blades and an engine to drive it. An airscrew for wing or power propulsion of a ship would be similar to that described, except that it might be preferable to use some sort of tower or tripod to support the rotor in place of the mast.

Returning to the question of how big an airscrew a ship can carry, it would seem reasonable to compare it with sails for the ship, because, when the wind is blowing, it can operate as a sail. Moreover, the wind will always have a strong effect on an airscrew-propelled ship, and part of the art of navigating such a vessel will be to extract as much free power from the wind as possible.

The 400 foot sailing ship *Preussen*,* the only large ship on which the author has data, could lift 8000 tons. The deadweight of a Liberty is 10,000 tons on the same length; so *Preussen* is roughly comparable to a Liberty. *Preussen* had 60,000 square feet of working sail, a moderate amount for her in view of the fact that she used to carry over half of it in Cape Horn gales. Assuming that sail area should be directly proportional to tonnage in this case, a Liberty should have 75,000 square feet of sail to make its rig comparable to *Preussen's*.

The wind thrust available to a sailing ship is proportional to the kinetic energy of an air stream having a cross section equal to its sail area and the wind's velocity relative to the ship. Similarly, the wind thrust available to a ship propelled by a windmill is proportional to the energy of an air stream having for cross section the swept area of the windmill blades. Both sails and windmills abstract only a small proportion of the wind's energy; so that one must be cautious in comparing sail area directly with windmill swept area. This is, however, what the author proposes to do. His chief justification is that those few windmill propelled boats with which he is familiar all had swept areas about equal to

*Data on *Preussen* and other sailing ships are from the works of Alan Villiers, mostly from "The Way of a Ship", Charles Scribner's Sons, 1953.

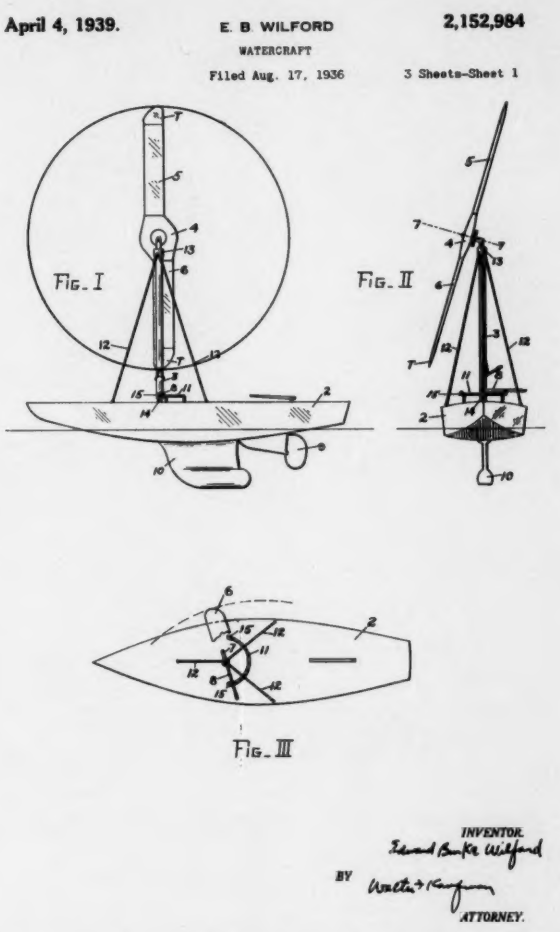



**Figure 3. Star class hull fitted with a windmill in place of sails, drawing from E. B. Wilford's patent.**

what their sail areas would have been, and that all behaved about like sail boats as to speed and angle of heel. Of course the design and pitch of the windmill, no less than the set of the sail, make a difference. However, with the knowledge now in hand, the simple comparison of sail area with swept area is the best available.

On the above basis, a (hypothetical) wind-propelled Liberty would require a windmill 309 feet in diameter to make it comparable with *Preussen*. This is a reasonable size for a 400 foot ship and would look about like figures 4a or 4b, depending on whether the area is all in one screw or divided equally between two.

Of these two configurations, the author believes that the second, with a screw forward and another aft, will prove to be the better. It has the triple advantage of reducing the windmill's size, placing the center of thrust lower and greatly improving the

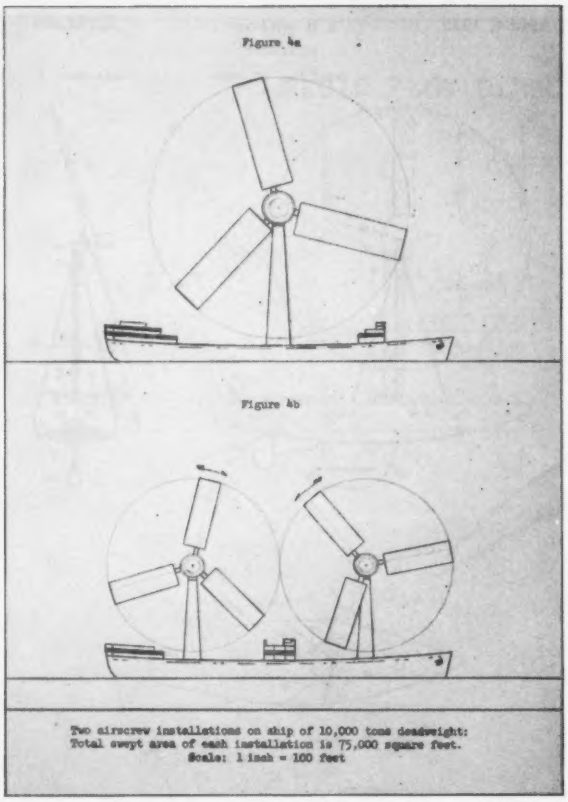


Figure 4a
Figure 4b
Two airscrew installations on ship of 10,000 tons deadweight:
Total swept area of each installation is 75,000 square feet.
Scale: 1 inch = 100 feet

**Figure 4. Liberty hull with 75,000 square feet of airscrew:**

**a. all in a single screw**
**b. equally divided between two screws**

maneuverability of the ship under both "sail" and power. This arrangement will entail a loss in efficiency when under power in a calm and when "sailing" directly before the wind, but its advantages are probably worth the price.

If a Liberty had no engine, one could expect from it a performance comparable to that of the big steel sailing ships of around 1900, which averaged seven or eight knots on long voyages. Compared with earlier ships, those of the 1880's to 1900's were undermanned and undercanvassed, for the sake of economy. The crew had to be small to cut expenses, and, as long as sails were worked by hand, the size of the crew limited the size of the sails. Nevertheless, these ships, of which *Preussen* is an example, made fairly good passages at average speeds of around seven knots, calms included.

A windmill-propelled ship, unlike a sailing ship, would not require a crew to work sails. The operation equivalent to shortening sail would be feathering the windmill, whose pitch would have to be controllable for other reasons, and feathering the windmill would be done quickly from the pilothouse by one man.

This new speed and ease of reducing sail makes it possible to consider windmill swept areas larger for the ship's size than the sail areas of later sailing ships. It would probably pay to give a Liberty 100,000 to 120,000 square feet, which means a single windmill of 357 to 391 feet diameter. See Figures 5 and 6 for the ship's resulting appearance. It is the author's present opinion that this is about the size airscrew that a Liberty-sized hull can be expected to carry.

The ideal efficiencies of airscrews of the above sizes propelling Liberty hull are given in Table I.

TABLE I.

| Swept Area of Airscrew | Ideal Efficiency | Diameter one screw (feet) | Diameter two screws (feet) |
|---|---|---|---|
| 75,000 sq. ft. | 0.73 | 309 ft. | 219 |
| 100,000 sq. ft. | 0.78 | 357 ft. | 252 |
| 120,000 sq. ft. | 0.80 | 391 ft. | 276 |

These are lower than the ideal efficiency on a Liberty of a 20 foot diameter water screw, which is about 0.84. Moreover, in the speed range where commercial ships operate, propulsive efficiency does not vary appreciably with speed. It is not possible to improve it by running the ship more slowly. With the size airscrews shown, the tabulated ideal efficiencies are constant over the ship's speed range.

As we have seen, however, the airscrews contemplated are large enough to make a ship sail well without any power from engines. In fact, such an airscrew-propelled ship can probably be made to sail better than the late nineteenth century sailing ships, because it will be able to carry as much "sail" as desirable, not being limited in this respect by the smallness of its crew.

Thus the airscrew size problem has a simple solution. Make it as big as the ship can carry. This will give the ship more "sail" when the wind is blowing and a higher propulsive efficiency under power.

By the same token, the most desirable amount of engine power to install in an airscrew-propelled ship is not large. The main functions of an engine on such a ship would be maneuvering, entering and leaving port, passing over calm areas, assisting in light winds, etc. The lower propulsive efficiency under power would discourage continuous use of the engine.

## MOST LIKELY USE FOR AIRSCREW PROPULSION

Thus an airscrew-propelled ship proves to have the characteristics of an auxiliary sailing ship, rather than those of a full powered vessel. Such a ship should be economical to operate, especially over long distances.

While the sailing ships were dying a lingering commercial death, some authors who liked them better than steamers wondered how much more useful they would be if some satisfactory means could be found to apply a small auxiliary power.

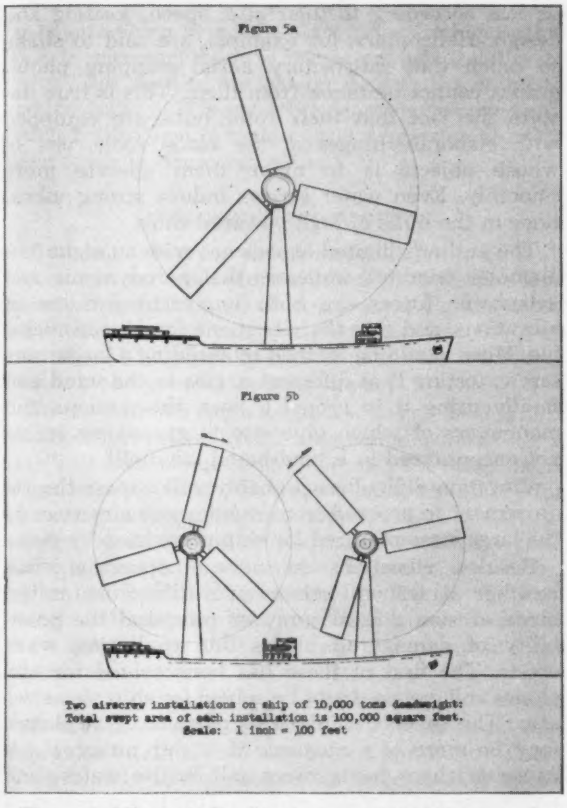


Figure 5a
Figure 5b
Two airscrew installations on ship of 10,000 tons deadweight:
Total swept area of each installation is 100,000 square feet.
Scale: 1 inch = 100 feet

**Figure 5. Liberty hull with airscrew of 100,000 square feet swept area:**
**a. all in a single screw**
**b. equally divided between two screws**

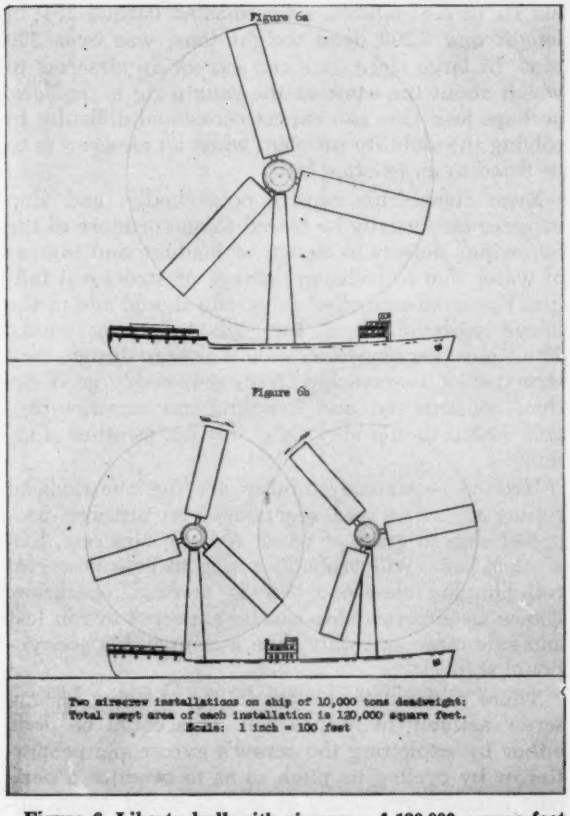


Figure 6a
Figure 6b
Two airscrew installations on ship of 10,000 tons deadweight:
Total swept area of each installation is 120,000 square feet.
Scale: 1 inch = 100 feet

**Figure 6. Liberty hull with airscrew of 120,000 square feet swept area:**
**a. all in a single screw**
**b. equally divided between two screws**

If they no longer had to wait days, as they often did, to go a short distance across the doldrums, their passages could be somewhat shortened by a small expenditure of energy. A slight shortening, moreover, is all that would be required to make them pay. A bettering of the eight knot average speed attained by the larger ships, combined with a smaller crew, would pay a modest fuel bill and put them back in business.

Heretofore, auxiliary sailing ships have not been commercially successful on ocean voyages. When such a ship is sailing, the propeller drags in the water. When it is steaming in a calm, the sailing rig drags in the air, and this latter drag is greater than most people realize. However, the airscrew would give to wind powered ships the extra push they need from time to time without dragging when not in use.

We have seen that, when put on a heavy ship, an airscrew is primarily a sail capable of using for propulsion a moderate engine power in the absence of wind. This makes it suitable for propelling ocean-going tankers. The most economical modern tankers are low powered ships, slow for their large sizes, with full bows and low speed-length ratios. Airscrew propulsion is a logical next step to make them yet more economical to run, or to give them higher average speeds with no increase in fuel consumption.

The commercial flexibility of an airscrew propelled tanker deserves mention. When demand for oil transportation is high, such a ship can burn fuel and go faster. When demand falls, it can stop burning fuel and still travel at a reduced operating cost.

## PRACTICAL PROBLEMS

The bulk of this article has been taken up with the theory of airscrew propulsion and with the use for it which the theory indicates. Now it is time to consider some of the practical problems of installing such a large screw on a ship and of operating it at sea.

A person confronted for the first time with this proposal is likely to wonder about the stability of a ship carrying so heavy an object as a large airscrew high off the deck. However, it is, in general, possible to design a ship with sufficient stability to carry a high weight. For example, the weight of the sail-

ing rig of *København*, a five-masted barque 354′ in length and 5,200 dead weight tons, was over 300 tons. In large ships, one can expect an airscrew to weigh about the same as the sailing rig it replaces, perhaps less. One can expect occasional difficulty in solving the stability problem when an airscrew is to be fitted to an existing hull.

Even steamships capsize occasionally, and ship capsizes can usually be traced to one or more of the following: defects in design or loading, and ingress of water due to collision damage or structural failure. For wind-propelled ships, one should add to the above mishandling of the sails in strong winds. Thus, most capsizes are due to lapses in design, construction or seamanship. With reasonably good design, construction and handling, an airscrew-propelled ship should stay right side up, as other ships do.

Related to statical stability are the questions of rolling in waves and reaction of an airscrew-propelled ship to gusts of wind. A large airscrew, like a set of sails, will probably prove to be a powerful roll-damping device when in normal operation. Hence an airscrew ship can be expected to roll less and ride more smoothly than a comparable conventional ship.

There also exists the possibility of using an airscrew actively to reduce roll. This could be done either by exploiting the screw's gyroscopic properties or by cycling its pitch so as to produce a periodic lateral force acting at the masthead which opposes the rolling moment. Of the two, the latter is probably preferable, because it requires only a sufficiently energetic pitch-control device, necessary in any case for maneuvering and for coping with strong gusts. On the other hand, use of gyroscopic forces would require a heavy and expensive set of trunnions and operating gear at the masthead to precess the propeller, gear useful for nothing else. Basically, the two functions of roll-stabilizing gyroscope and propeller are not compatible with each other. For maximum effectiveness, the latter requires rotation in a vertical plane; the former, rotation in the horizontal plane. If the same rotor were used for both, it would have to operate in a compromise position efficient for neither purpose.

Many gales of wind include gusts of sufficient strength to endanger an airscrew-propelled ship or its propeller. In dealing with such gusts, the problem is to spill the excess wind quickly. The best solution appears to be a fast-acting pitch control device, such as are routinely fitted on large airplane propellers. Such a device would be required in any case for maneuvering the ship in close quarters. An airscrew ship should thus have no trouble weathering gusts which would have endangered a sailing ship through its inability to shorten sail in a matter of seconds.

A more difficult problem than stability is vibrations. All sorts of large air machines vibrate, more or less according to their size, speed, loading and design. Helicopters, for example, are said to shake so much that satisfactory aerial mapping photographs cannot be taken from them. This is true despite the fact that their rotor hubs are equipped with elaborate hinges at the blade roots, one of whose objects is to make them operate more smoothly. Even water screws induce strong vibrations in the hulls of high powered ships.

The author's limited experience with an eight foot diameter windmill indicates that aerodynamic and gyroscopic forces are both important exciters of vibrations, and that the vibrations can be considerable. More would be learned by building a larger airscrew, testing it at different angles to the wind and finally using it to propel a boat, the motions and maneuvers of which give rise to gyroscopic forces not encountered in a land-based windmill.

Vibration difficulties probably will impose the requirement to proceed from smaller size airscrews to the large sizes required for ship propulsion by steps.

Besides vibrations in normal operation, bad weather at sea will create such difficulties as ice, blade erosion due to spray or rain, and the possibility of damage to blades due to hitting wave crests. The first of these has been solved for airplanes and can no doubt be solved for ship airscrews also. The second, while also present in airplanes, may be more of a nuisance to a ship airscrew because of there being more salt in the water, and sometimes more water as well. This is a question of materials and blade speeds, which it will take some experience to settle. It will likewise take experience to determine how low it is safe for the blade tips to come on various types of ships.

Before leaving the field of practical problems, the problem of hull shape should be mentioned. The later sailing ships had hulls not unlike those of present-day tankers and dry cargo ships, leading the author to believe that airscrew propulsion will require no radical change in hull form. However, in the choice of hull form and internal arrangements two principles should be observed.

First, the hull form should be suitable for a higher speed than the engines can provide. At times, there will be sufficient wind to drive an airscrew ship faster than any commercially feasible propulsion machinery, and it would be well to have a hull shape able to take advantage of such situations. Such high winds are invariably accompanied by big seas, and fine-ended ships behave better than full ones in a seaway. Finally, experience with the later sailing ships demonstrated that full-ended ships make excessive leeway as compared with finer hulls, especially undesirable when the ship is near shore. As a guess, a hull suitable for speed-length ratios in the range 0.8—1.0 (16-20 knots for a ship 400 feet on the waterline) would be a reasonable compromise between the requirements for capacity, speed and reduction of leeway.

Second, any airscrew ship will require the ability to ballast down to a safe draft before going to sea. This is necessary both to insure enough stability to carry "sail" and to put enough hull in the water to reduce leeway. It is not a burdensome requirement, being no problem in tankers and a question of extra deep tanks in dry cargo ships.

### ENGINEERING DEVELOPMENT

How many smaller airscrews will have to be built to achieve, for example, a successful three hundred footer, is hard to predict in advance. On the other hand, it is less difficult to determine what the next step should be, since to do this it is only necessary to know the present state of the art.

To the author's knowledge, the largest boat which has been propelled by an unpowered windwill is a star boat hull, about 22 feet long. On the other hand, some sizeable windwills have been built ashore for electric power generation, notably the 175 foot diameter wind turbine erected in 1940 on Grandpa's Knob, a mountain in Vermont. Experience with this latter has been well reported by Palmer C. Putnam,* a leader of the project. Figures 7 and 8 show how it was built and help give one a feel for large wind machines.

Hence the greater lack is of marine experience, rather than airscrew experience, and the next marine installation should not be too ambitious. There are probably useful lessons to be learned from an airscrew-propelled boat of modest size, say twenty-five feet long with an airscrew of diameter slightly less than the boat.

After accumulating airscrew performance data and operating experience on a yacht-sized vessel for about a year, it should be possible to estimate with sufficient accuracy the commercial value of airscrew ship propulsion. Since airscrew propulsion is primarily wind propulsion, it will become more attractive as, in years to come, the price of fuel goes up. The author is of opinion that it would probably pay now in some important trades, such as from the Persian Gulf to Europe. It would also have the effect of making small ships better able to compete with large ones in long distance trades.

The development work required, plus a useful amount of wind tunnel experimentation, could be done for less than one million dollars, a sum insignificant beside those being spent on nuclear merchant ship propulsion. The program could be started with much less. Moreover, the promise is operating costs that are lower, not higher, than current ones.

In addition to economic benefits, successful airscrew ship propulsion can be expected to bring with it some non-economic ones. For one thing, it will make the operation of merchant ships more interesting to those engaged in it. No longer will a merchant shipmaster go plodding across the ocean in

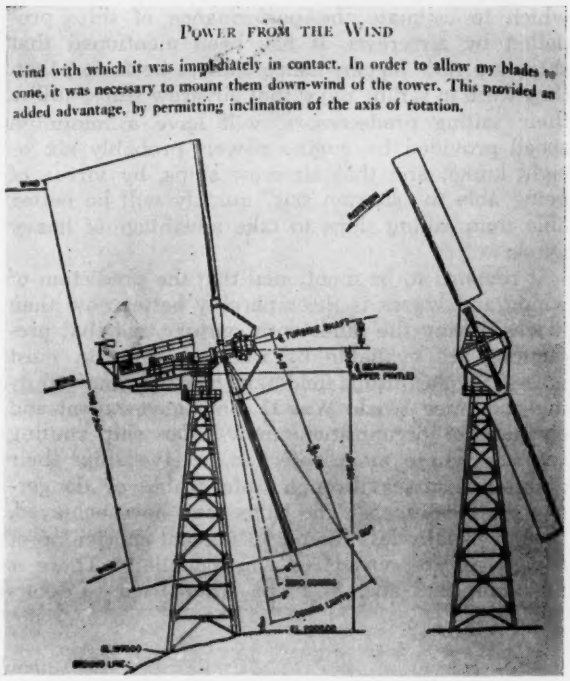

POWER FROM THE WIND
wind with which it was immediately in contact. In order to allow my blades to cone, it was necessary to mount them down-wind of the tower. This provided an added advantage, by permitting inclination of the axis of rotation.

**Figure 7. The Grandpa's Knob 1250-kilowatt test unit of the Smith-Putnam Wind Turbine.**

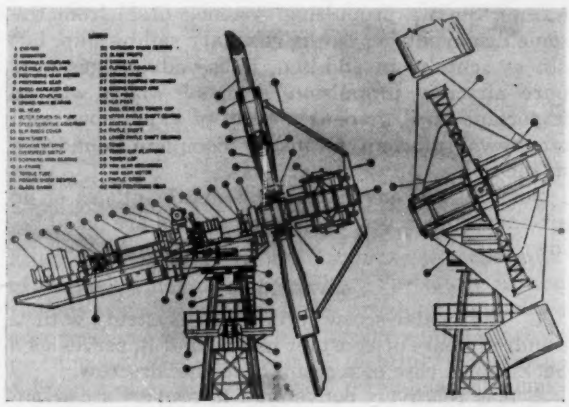


**Figure 8. Schematic detail aloft of the 1250-kilowatt test unit of the Smith-Putnam Wind-Turbine erected on Grandpa's Knob.**

something with a definite and low maximum speed. Instead, he will be going slowly one day and very fast the next. By means of study and good seamanship, a skipper will be able to shorten his passages appreciably.

### A SUPPORTING SERVICE: WIND PREDICTION

While on the subject of shortening passages, it should be mentioned that historical sailing ship passages are extremely conservative standards by

* "Power from the Wind" by Palmer C. Putnam, D. van Nostrand Company, Inc., 1948.

which to estimate the performance of ships propelled by airscrews. It has been mentioned that ships are now bigger, hence tend to be faster, than they were in sailing days; that airscrew ships, unlike their sailing predecessors, will have a minimum speed provided by engine power, probably six or eight knots; and that airscrew ships, by virtue of being able to "shorten sail" quickly will be better able than sailing ships to take advantage of heavy winds.

It remains to be mentioned that the prediction of winds and waves is incomparably better now than it was during the nineteenth century and that predictions are available by radio to ships in most places. Strides in this field have been enormous during and since World War II. Both government and commercial organizations now offer ship routing services whose main object is to give ships their optimum courses through unfavorable or dangerous sea conditions.* The gains they have achieved, though usually less than a 10 percent shortening of a passage, are considered worth while.** There is no doubt that such services, when used to determine optimum routes for ships propelled by wind would result in far greater gains in performance.

### CONCLUSION

There is every hope of success in developing economic ship propulsion by airscrew. Naval architecture is sufficiently advanced to undertake the building of such ships, and weather prediction is already adequate to make the best use of them. It may be that the time is ripe for a new era of wind-powered navigation.

The wind is a force uniquely well suited to driving ships, as shown by the persistence of the sail. Sails have been in continual use for all recorded history, putting them in a class with such basic devices as the wheel and showing them to be based on sound physical and economic principles. The ship propulsion airscrew, being based on those same principles, has only to be perfected and its usefulness is assured.

*H. O. No. SP 1, "Application of Wave Forecasting to Marine Navigation", by R. James, July, 1957.
**H. O. No. TR 53, "An Evaluation of the U. S. Navy Hydrographic Office Ship Routing Program", by R. James and G. Hanssen.

### POST SCRIPT

While this article has been concerned with ships propelled by airscrews alone, there is also the possibility of ships equipped with both air and water screws. Such a propulsive system suffers from the same disadvantages as the auxiliary sailing ship, but not as acutely. In addition, it has advantages over pure airscrew propulsion, some of which will be important until there is a body of experience with airscrews sufficient to justify complete confidence in them.

Some of the advantages and disadvantages of an air-and-water screw propulsion system are listed below:

### ADVANTAGES

1. The water-screw propulsion system, with a hundred years of constant use behind it, serves as a backstop in case of a casualty to the airscrew.

2. It is relatively convenient to convert a conventionally propelled ship to the mixed system, because this only requires adding the air machines.

3. A water screw is more efficient in light airs, and much more efficient when the ship is constrained to hold a course directly to windward. It is especially effective in getting off a lee shore, when a pure airscrew ship would probably have to tack like a sailing ship.

### DISADVANTAGES:

1. A greater capital investment is required, because one must pay for both water and air screws, and a fairly elaborate power transmission for one of them or the other. (This applies chiefly to new construction, not conversion.)

2. The airscrew will be a drag when not in use, though only a fraction as great a drag as a sailing rig.

3. The water screw will drag seriously when not in use, forcing a choice between:

a) fitting a feathering water propeller (expensive), or

b) running the water screw at all times at a speed proportional to the ship's. This will prevent complete shutdown of the water-screw plant, even when there is plenty of wind, adding to the operating cost.

The first two advantages of the mixed system are in the author's opinion of sufficient weight to insure its use for pioneering installations of large airscrews.

"THE MARINE ENGINEER AND NAVAL ARCHITECT"

# *GUIDED MISSILE DESTROYER* DEVONSHIRE

**ACKNOWLEDGMENT**

*Prepared by the staff of "The Marine Engineer and Naval Architect," this article appeared in their August 1960 issue from which it is reprinted.*

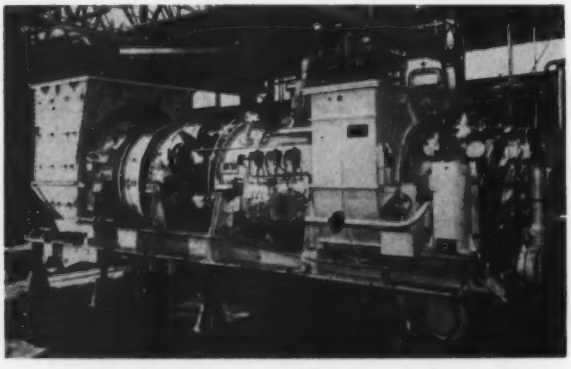
**H M.** GUIDED-MISSILE destroyer *Devonshire* launched by H.R.H. Princess Alexandra from the yard of Cammell Laird & Co. (Shipbuilders & Engineers) Ltd. is the first of four County-class destroyers. The ship was laid down in March 1959 and is expected to commission early in 1962. Her three sister ships *Hampshire*, *Kent* and *London*, building at Clydebank, Belfast and Wallsend respectively, are expected to join the fleet by the spring of 1963.

The County-class destroyers are the largest warships to be ordered for the Royal Navy since the end of the Second World War and have a length of 520 feet, a beam of 54 feet and a standard displacement of over 5,000 tons. They will be very powerfully armed with four 4.5 inch radar-controlled guns in two twin-mountings forward, four 40 mm. Bofors anti-aircraft guns in two twin mountings amidships, two Seacat close-range guided missile systems abaft the after funnel and a twin launcher on the quarter deck for the Seaslug sea-to-air guided missile. They will be the first combatant ships to be armed with the Seaslug. Anti-submarine armament will comprise two triple torpedo tubes and a Westland Wessex helicopter, the first type of helicopter to be fitted as a hunter-killer. Ship stabilizers will facilitate the operation of the helicopter in bad weather. The latest air and surface warning radar will be provided, as well as an operations room of a new design with electronic plotting facilities. A new style of bridge affords the captain a clear all-round view combined with maximum protection.

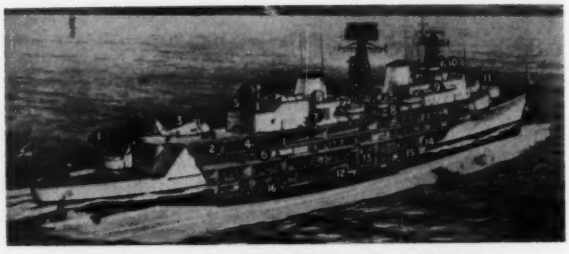
**The official model of the new County class ships. The profile will be acceptable to critics of other post-war construction.**

These ships have three main roles (1) Escort duties with a task group, including the ability to provide guided-weapon anti-aircraft defense for the group and to augment its anti-submarine capability. (2) Offensive operations as part of a task unit of light forces, with the ability to bombard in support of land forces and to attack light forces with gun fire. (3) Police duties in peacetime in any part of the world. The high efficiency turbines will give the ships the ability to operate on their own for long periods.

The ship's company is expected to number about 33 officers and over 400 ratings. The mess decks are fitted with bunks and provide the maximum recreation space in each mess. Large cafeteria dining halls are served by an all-electric galley and full air-conditioning is to be applied.

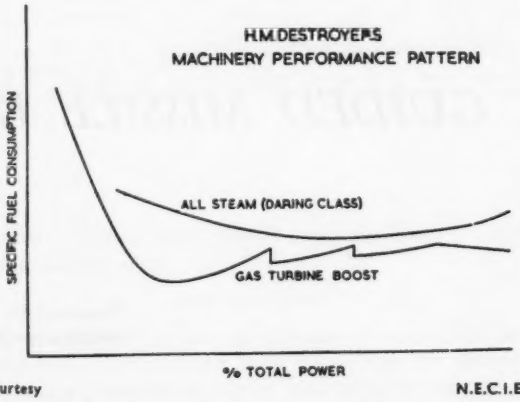


**An A.E.I. G6 marine gas turbine of 7,500 bhp. Two of these can be applied to each shaft through Vulcan-Sinclair Fluidrive couplings to provide 100 per cent increase in power.**



**Cut-away sketch of H.M.S. 'Devonshire'**

**1. Seaslug launcher. 2. C.P.O.'s Mess. 3. Helicopter deck. 4. Crews dining hall. 5. Seaslug control radar. 6. Missile stowage. 7. Seacat launchers. 8. Homing anti-submarine torpedo tubes. 9. Inflatable liferaft. 10. Enclosed bridge. 11. Twin 4.5 in. dual-purpose guns. 12. Gas turbine room. 13. Gearing room. 14. Boiler room. 15. Steam turbine room. 16. Fuel tanks.**




Courtesy N.E.C.I.E.S.

**Showing how the use of booster machinery can result in a "flat" fuel consumption curve over a very wide power range.**

GAS TURBINE BOOSTER PLANT

The twin-screw machinery is to develop a total of 60,000 shp for a speed of about 32½ knots. Each shaft will be driven by a combination of a high pressure double-reduction steam turbine of 15,000 shp which provides the main source of power for cruising and normal speeds, and two G6 gas turbines each developing 7,500 shp and so arranged that either form of propulsion can be used separately or together. This revolutionary propulsion system has been developed jointly by the Admiralty, the Yarrow-Admiralty Research Department, the Metropolitan-Vickers branch of Associated Electrical Industries Ltd. and Fluidrive Engineering Co. Ltd. The steam and gas turbines, gearing and control gear were designed at the Trafford Park works of A.E.I., where all these elements, with the exception of one of the steam turbines for the *Devonshire* (which is being built by Cammell-Lairds) have been made, and where a lengthy series of full-scale shop trials were carried out on the prototype set of equipment.

The 7,500 shp G6 gas turbines may be considered to be the latest step in the progression from the original Metro-Vick 2,500 hp Gatric, which in 1947 powered *M.G.B.*2009, the world's first gas turbine vessel. This was followed by the 4,500 shp G2 sets which were fitted in H.M.F.P.Bs. *Bold Pathfinder* and *Bold Pioneer*. In these the gas-generating section was similar to that of the Beryl aircraft jet engine.

The "boost" concept has attractive features from the aspect of nuclear warfare, as a ship so equipped can, in emergency, use her gas turbines alone to get under way rapidly, for they can achieve full power very quickly. In the meantime the boilers can be flashed-up and the steam turbines brought into service as required. Alternatively, when cruising on steam turbines alone, speed can be increased by starting up the gas turbines and doubling the power available at the propellers. As the steam turbine

and the two gas turbines are geared to the same propeller shaft, the transmission involves certain advanced features such as S.S.S. automatic-engaging clutches for the gas turbines and a reversing gear, so that the ship may be maneuvered on the gas turbines alone. Another advantage is that since there is an alternative source of power to the steam plant, the number of stand-by auxiliaries can be reduced.

The gas turbines are inevitably tremendous consumers of air, calling for large inlet and exhaust ducts for restriction of the breathing due to limitations of the duct size which has a serious effect on the turbine performance. In this case a satisfactory compromise has been made and an exceptionally low headroom in the engine room has been achieved, thus providing greater living spaces above.

To summarize, the steam plant provides cruising power with a considerable endurance and a maximum of about 25 knots, while the gas turbines provide the boost speed with an acceptable fall-off in efficiency for higher powers, when, of course, endurance is not so important. Gas turbines offer the virtues of compactness, high power/weight ratio, quick starting and the ability to develop full output soon after cold start. The fuel consumption of these machines is, however, relatively high and they are thus only useful in conjunction with other more efficient prime movers. It has been stated that a destroyer develops more than 20 per cent of its total power for less than four per cent of its service life. The booster gas turbines, therefore, confer major benefits in machinery size and weight.

Inspection of the exploded view of the ship reveals that there are four main machinery spaces. The boiler room (14), with uptakes discharging through the forward funnel, the steam turbine compartment (15), a separate gearing room (13) and finally the gas turbines room (12). The exhaust from the gas turbines is led through the after funnel.

The nuclear sub, ***Seadragon***, which nosed its way beneath icebergs in blazing a possible military/commercial route through the Northwest passage, has racked up a technical "first," according to Minnesota Mining and Manufacturing Company. Aboard is an undersea video tape recorder, which will magnetically capture under-the-ice vistas seen by externally installed TV cameras. Playback—on the same RCA TRT-1A used by commercial TV stations—will be used in evaluation, education and training on safe submarine routes. The transistorized recorder, a joint Navy-RCA development, fits a torpedo rack; uses 2600-ft. reels of two-in. 3M tape.

—From RESEARCH/DEVELOPMENT
November 1960

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ROBIN D. S. HIGHAM

# *WILLIAM H. WEBB: FOREIGN WARSHIP CONSTRUCTION AND THE CIVIL WAR 1857-1865[1]*

**THE AUTHOR**

*was born in England and educated in that country and in the United States. He served in the Royal Air Force as a pilot, 1943-1947. He attended the University of New Hampshire and graduated* cum laude *from Harvard in 1950. After graduation he taught at the Webb School of California, 1950-52 and took an M.A. at the Claremont Graduate School. Did graduate work at Harvard, 1952-54, and assisted Prof. Robert G. Albion. Taught at the University of Massachusetts, 1954-57, and at the University of North Carolina since that date. He obtained Ph.D. in History from Harvard, 1957. He is the author of "The Port of Boston and the Embargo, 1807-1809." THE AMERICAN NEPTUNE, July 1956; "Pioneer British Airlines in West Africa," ESSO AIR WORLD, 1958. His Ph.D. dissertation was on the development of British overseas airlines, 1918-1939/40. He has a manuscript in progress on British rigid airships. He is now an Assistant Professor at the University of South Carolina.*

ONE OF THE MOST unusual and least explored developments in American shipbuilding is the creation of foreign warships in the United States. In the last days of the New York City yards after the peak of 1855, vessels were produced for the Egyptians, the Russians, the Italians and the Japanese. William Webb built notable wooden ships for both the Russian and the Italians. For the former he produced the largest wooden vessel of her day. For the latter he constructed two advanced ironclads, yet for his own country he contracted for but one naval vessel throughout the Civil War, and this was incomplete when Lincoln was assassinated, and it was sold abroad when finished.

William H. Webb is best known for his clipper ships and Atlantic packets and as the rival of Don-

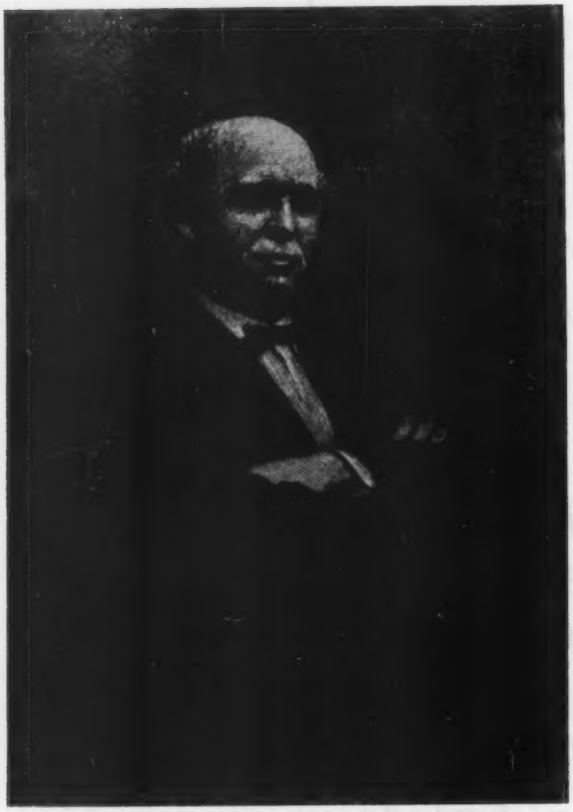


**Figure 1. William Webb** *Harper's Weekly*

ald McKay of Boston. Both of these great shipbuilders had been trained by William's father Isaac. In 1840 the younger Webb took over the management of his father's yard on the East River. [2]

At that time steam was just coming into use for ocean-going vessels and the younger Webb found himself still safe in building sailing ships. American vessels had the advantage economically as they cost as much as 30 per cent less than those built in Europe, while steam was generally too expensive for wide use. But times were changing. By 1851 William Webb had built eight steamship hulls, yet the California gold-rush still left the construction of clippers and other sail good business. In 1855 the New York yards were at their peak. Some 31 of them employed 2313 highly-paid craftsmen and their annual production was valued at $3,538,000. However, the next year the Peace of Paris, settling the Crimean War, saw freedom of the seas accepted and the chances of American profits from shipping became less certain. At the same time considerable strides were being taken abroad in iron shipbuilding and the American cost advantage began rapidly to dwindle away. In 1857 a severe depression hit the country. The major New York yards then attempted to turn to iron and most installed expensive machinery as by this time wooden steamers, already rapidly losing popular favor on the Atlantic, were costing 25 to 35 per cent more in America than if built abroad. It also became necessary for builders to scurry about for orders. [3] Webb's troubles were added to by the Southern success in depriving the Collins Line, Cunard's American rival, of its subsidy causing it to cease operations in 1858. At the same time a rearrangement of the lines to Panama and the West Coast followed, but was not completed until later the next year, using ex-Collins ships.

Webb was fortunate in that he had always had a number of foreign orders, and he was tied in financially with the Pacific Mail (for whom he built 16 steamers), and possibly also with the Novelty Iron Works run by Daniel Allen, son-in-law of Commodore Vanderbilt. The Russians had earlier had the steam paddle warship *Kamschatka* constructed by an American builder. Thus Webb was but following a previous pattern when, after the United States rejected his design for a steam frigate, said to have been completed in 1851, he went abroad to sell it. He found in the Russians not only people who were anxious to build up their navy after the ignominious blockade of the Crimean War, but who were willing to spend the required $1,250,000 for such a vessel. In addition, Webb acquired an order for the corvette *Japanis*. She was laid down in Spring 1857, while her larger consort was not begun until 21 September. [4]

Webb's yard between 5th and 7th Streets on the East River was soon busy with the Russian corvette *Japanis* (or *Japanese*). She was a shallow draft vessel of 1400 tons (2000 tons displacement) [5] for use on the Amur river and drew only 14 feet fully loaded. Two hundred and fourteen feet on the spar deck, 36 feet 6 inches in beam and with a depth of hold of 17 feet 6 inches, as with all of Webb's foreign warships, she was fitted with engines from the neighboring Novelty Iron works. These had pistons of 51 inches diameter and a stroke of 3 feet; they drove a 12 foot 6 inch diameter propeller and were supplied with steam from two flue boilers. *Japanis* was fitted by the Russians with four medium thirty-two pounders on each side and one 18-inch pivot fore and another aft. In addition, she had four large quarter boats and a launch fitted with a howitzer for use in amphibious work. Compared to the maximum of about $80,000 for clippers of the day, her $250,000 for a vessel of 1400 tons indicates how much more expensive and more heavily constructed warships were even in those days, even at depression prices. *Japanis* left New York in April 1858 and was delivered by one Captain Hall to the Russians at Hong Kong.

*General-Admiral* of 7,000 tons displacement (5000 tons 1864 measurement) was to take two years to complete. Ordered as a ship of the line, Dr. Ridgely-

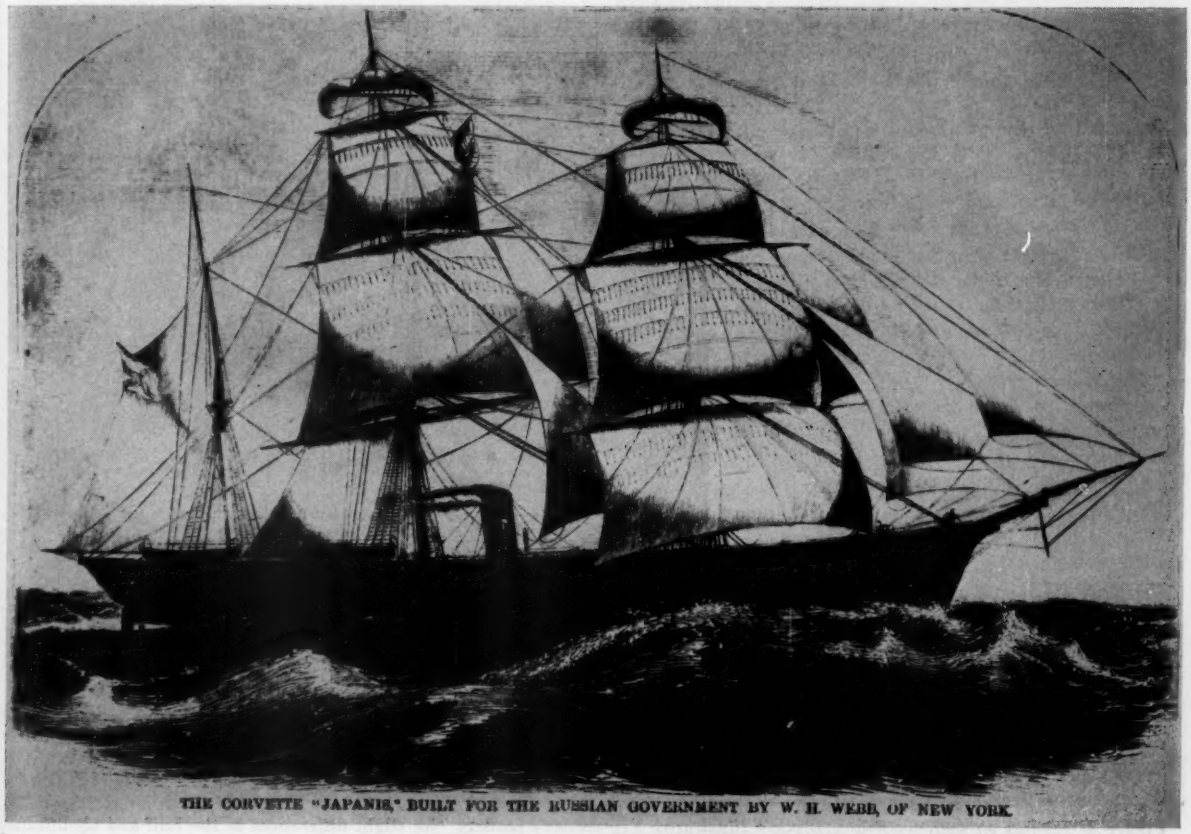



**Figure 2.** ***Japanis*** **as seen by a** ***Harper's Weekly*** **artist. Compare this with the next illustration.**

Nevitt of the Webb Institute says that Webb redesigned her as a large frigate. Laid down in September 1857, she was launched a year later and sailed for Russia in August 1859. At the time she first entered the water she was the largest wooden vessel afloat and was exceeded in size only by the ill-fated iron *Great Eastern*. She was stoutly built of live and white oak and measured 307 feet on the spar deck (325 feet overall), had a beam of 55 feet, the same as U.S.S. *Niagara*, [6] and a depth of hold from spar deck to keel of 34 feet. Her lower deck was pierced with 44 ports along the sides and two in the stern, while the spar deck had 30 broadside positions and four large ports forward and four aft. On the gun-deck she mounted 40 large shell guns and on the spar 20 long guns and two pivots. These guns, of course, were not fitted until she reached Russia. At the time of her launching (21 September 1858) she had aboard some 3,000 persons whose cheers were replied to by the more than 10,000 assembled for the ceremony. Her fine lines allowed her to enter the water so gracefully that those aboard were not aware of the fact.

Once in the stream she was taken in charge by tugs and moved to Nicholson's great balance dock at the foot of Pike Street. This was what today would be called a floating dock and was the only integral one in New York. Unlike its rivals, it was a single structure of iron with three tanks. The main was 200 feet in length, while at each end were 75-foot tanks. When small vessels used the dock, only the central tank was flooded and then pumped out again, but for a ship of *General-Admiral's* size, the whole system was employed. It was known as a balance dock because the smaller tanks were used for trimming. [7]

In the floating dock, *General-Admiral* was coppered, a task which had hitherto been done by careening. The illustration of her in dock shows that she had the fine lines of a clipper with flat floor, full bilge and sharp ends. In fact, though she was fitted with two steam engines of a nominal 800 horsepower each (producing, in fact, a total of nearly 2,000) transmitted to a 19-foot 6-inch Griffiths patent propeller which could be raised out of the water, she was expected to make 14 knots under sail. Sometime in January 1859 she was floated out of the balance dock and over to the Novelty Iron Works for her engines and six water-tube boilers to be installed, a job taking several months.

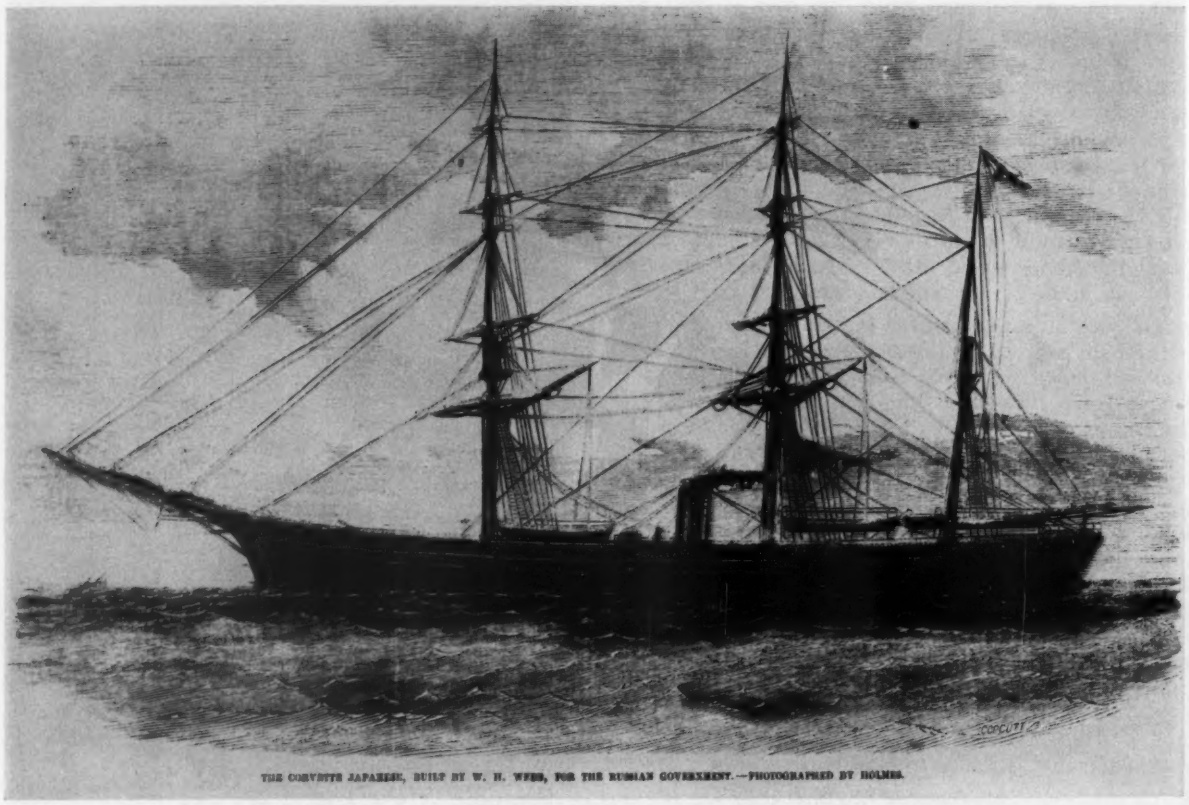



**Figure 3.** *Japanis* **as seen by** *Frank Leslie's Illustrated Newspaper's* **readers. Not slight differences in the hull and significant difference in the rig of the foremast. As this was taken from a photograph by Holmes, it must be presumed to be the more accurate.**

On 4 May she proceeded down the East River in charge of tugs until Governor's Island was abeam, when they were cast off and she proceeded down the Bay on her own. After a successful trip in which the only super-cargoes were Webb and Captain Crown, the Russian naval supervisor, she returned and docked at the wharf at the foot of Canal Street. After several more trials, coaling and storing, she sailed from New York in August, stopped at Portsmouth, England, to coal, and with the Grand-Duke Constantine aboard sailed from there on 5 September for Cronstadt. What happened to her thereafter remains a mystery. She did not take part in the Russian visits to the United States in 1863-64 [8] and no further information on her is available. Yet, in other hands than those of the tsarist navy, she could have been a useful, if not a formidable weapon, especially as a raider.

After the launching of *General-Admiral* Webb's yard appears to have been hard put to find orders. As far as is known he started no new vessels in 1859. In 1860 he began the steamship *Constitution* and five others, but in 1861 laid down only two Italian frigates; he had three orders in 1862, seven in 1863, and none for the years 1864-1868, and then only one in 1869. [9] In the latter year he retired, but he did not die until 1899. This decline may be explained by the rising cost of labor, the arrival of cheaper European iron vessels, the flight from the flag of American merchant vessels as insurance costs rose due to the raiders, and finally to the high taxes which made the shipyards untenable. But what is perhaps most surprising is the fact that a major shipbuilder remained employed only upon his own work, and foreign warships at that, during a conflict in which the Federal government was badly in need of ships. His one great contribution to the Union navy, the ram *Dunderberg,* was not completed until after the end of the war and was almost at once sold to the French. Except for monitors, Webb had as great experience as any American constructor, but he was not as well-equipped as European yards in a transitional period.

The years 1859-1869 were years of change and challenge. They began with the launching by the French of the ironclad *La Gloire* and saw a continual naval evolution to the all-metal ship with rifled guns. *General-Admiral* was in the older tradition which had not yet recognized the power of rifled guns and the destructiveness of their shells in

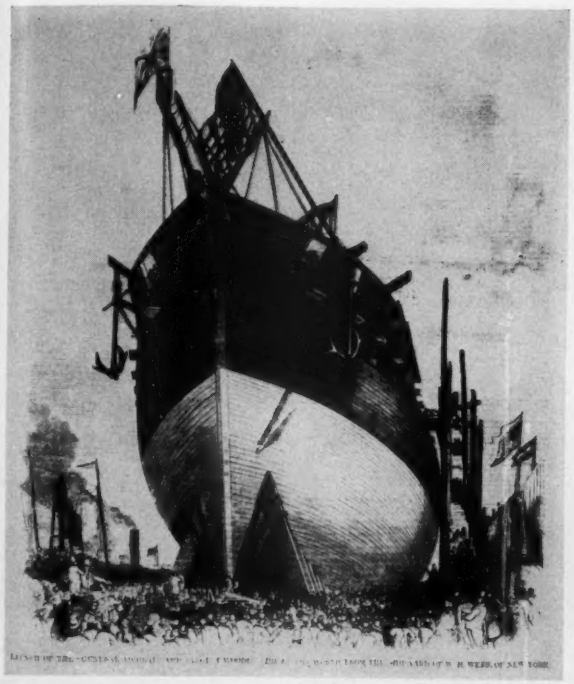


**Figure 4.** *General-Admiral* **as seen by the** *Harper's Weekly* **artist. Either this gentleman was not very familiar with ships, or he was not present at the ceremony at which she was launched. The bluff-bowed vessel shown here could hardly have attained 14 knots under sail.**

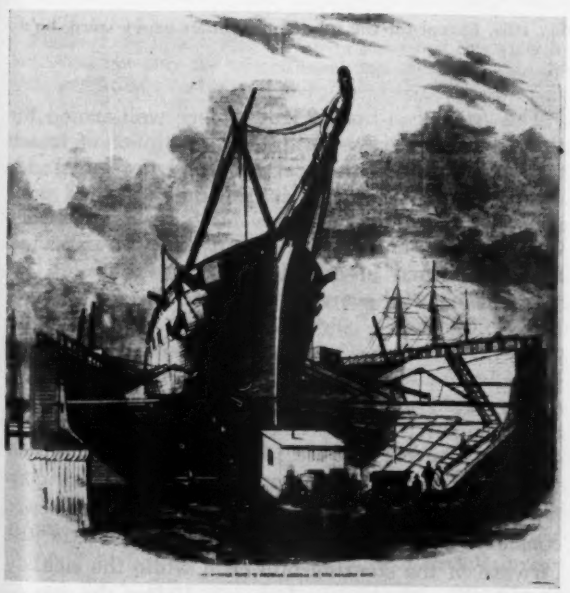


**Figure 5. Compare this view from** *Frank Leslie's Illustrated Newspaper* **with that from** *Harper's.* **The sleek clipper-like lines are quite evident. Of historical interest here also may be seen the floating or balance dock, the copper sheathing being placed in position, and the shear (or sheer) legs to be used in stepping the masts in** *General-Admiral.*

wooden ships, despite the supposed lesson of Sinope in 1853. Webb's new Italian frigates only became ram-fitted ironclads after the *Monitor-Merrimac* battle of 9 March 1862 emphasized these necessities. [10]

After delivering *General-Admiral* to the Russians, Webb went on another tour of European capitals seeking further orders. His visit coincided with the expansion of the Kingdom of Sardinia into Italy and he came home with contracts for two frigates for the brand-new Royal Italian Navy—*Re d'Italia* and *Re di Portogallo.* He acquired this work in 1860 and spent the remainder of the year and much of 1861 drafting plans for the two vessels. The keel for *Re d'Italia* was not laid until 21 November 1861 and that for her sistership not until some weeks later.

In general, building must be presumed to have followed the usual course with the wooden ribs being attached to the keel, beams fixed in place, all being reinforced with iron straps, and the whole gradually sheathed over in oak. [11] But in the course of construction a bomb proof deck was fitted and it was decided that she was to be partially armored.

On 18 April 1863 a crowd of at least 10,000 collected at the Webb yard at the foot of East 7th Street. They inspected *Dunderberg,* then on the ways, until shortly before 10 a.m. Then they gathered about *Re d'Italia* while 1,000 Italian beauties, local New York girls, boarded the ship for the actual ceremony. At 9:50 shores were knocked out and wedges driven in. Five minutes later she started down the ways on her own, without the forward cradle. As she slid into the water amid the usual cheers, the Italian consul's wife leaned over the bow and smashed a bottle of champagne on her. Once in the stream, tugs took her to the Novelty Iron Works for engines, boilers and the fitting of the lower belt of 4½-inch iron armor plate, the remainder being carried as ballast for the Atlantic crossing, to be fitted in Italy upon arrival.

*Re di Portogallo* ( *No. 124* to the Webb hands) was about two months behind her sistership in April, but was not in the end launched, owing to strikes and the riots of July, until 29 August. Both ships were of 294 foot length (275 feet between perpendiculars) with a beam of 55 feet and a depth of hold of 30 feet 6 inches. By the inflationary carpenter's measure they were of 5500 tons, but by customs house computation they would have been about 3500 tons. In standard (1865) tonnage they were 4250 tons, nearly the same as *General-Admiral.* It was said, however, that fully loaded for sea they displaced 6100 tons apiece.

At the time these ships were fitted out in the Fall of 1863 a number of foreign warships were in port and they became objects of curiosity to officers from the Russian fleet and French, British, Spanish and Swedish warships who were on occasion at anchor at New York.

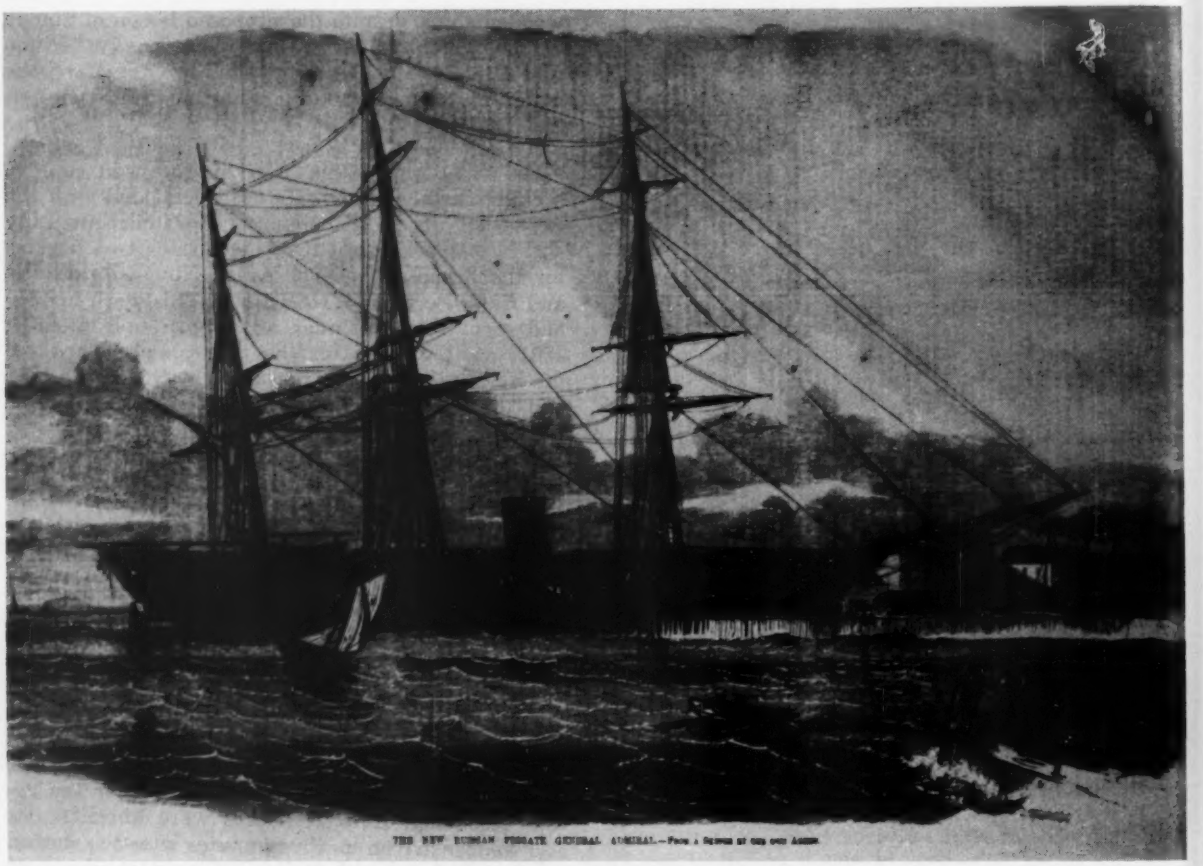
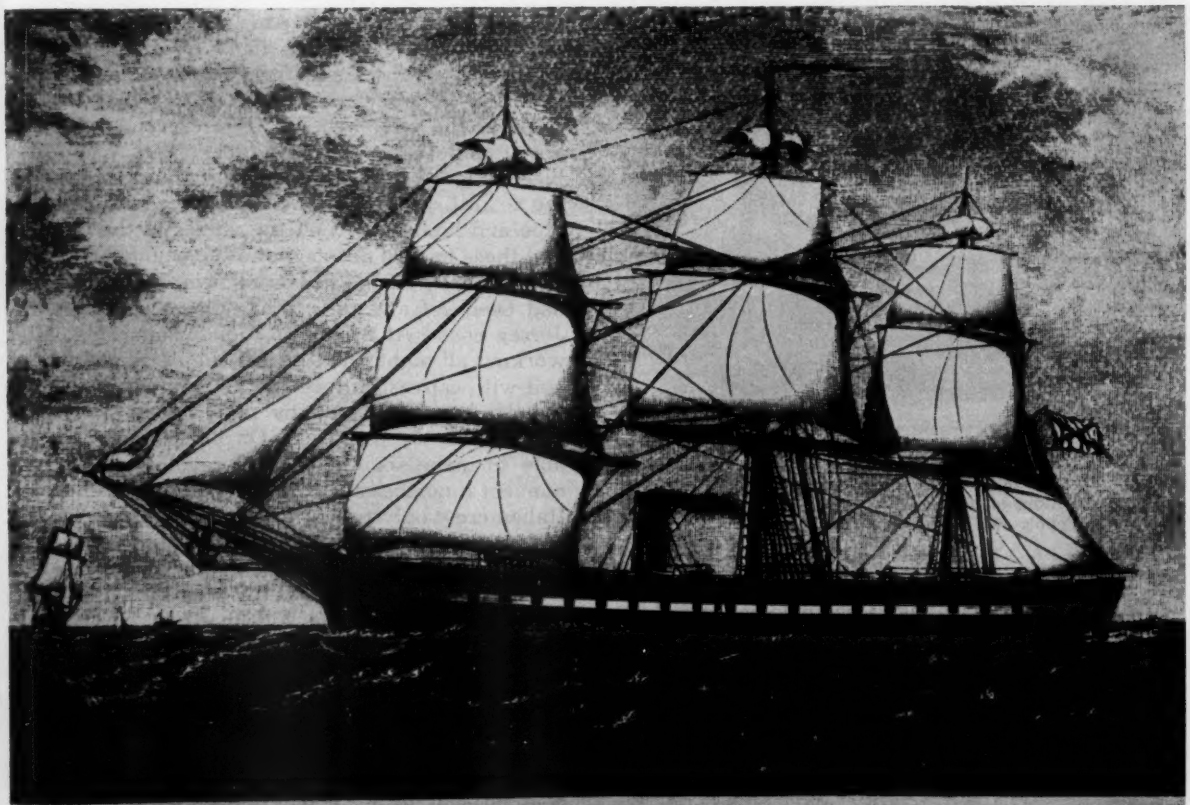


**Figure 6.** *General-Admiral* **as seen by** *Frank Leslie's* **artist in May 1859. Except for the funnel and rather heavy stern, holding guns, she could be taken for a clipper.**

On 4 November the Italian battleship *Re Galantuomo* arrived with a crew of 350 for *Re d'Italia*. The former was an old wooden 58-gun ship of 3500 tons and a crew of 740 which had lately been converted in the Neapolitan yards to a steamer, but without any of the usual strengthening of the hull for such a conversion. She was, moreover, of the old bluff-bowed type and her passage from Gibraltar via Bermuda lasted 46 days. At the same time another Italian steam frigate, *Don Giovani*, arrived in Boston for a social visit. In commenting on these arrivals the New York HERALD noted that it was surprising to Europeans that in the midst of a major war the United States could afford to build first-class ships for foreign navies. The Italians were also modernizing their navy with four ironclads being built in French yards. As the Italians owed a good deal of their newly-won independence to the Emperor Napoleon III, they were forced to allow the French to dictate much of their naval life. The latter insisted on testing the armor which Webb was to use on his frigates and rejected it, but in the end the New Yorker was permitted to use his own plates.

The American-built frigates were well-armed for their day with provision for 40 rifled guns, of which ten were to be on the spar deck and the remainder on the gundeck. The sides of the hull had considerable tumble-home above the waterline in order to present an angle to shot, and this was expected to be increased in usefulness by the ultimate armor plating. Nor were creature comforts neglected. The captain had a large cabin on the after gundeck; the wardroom was on the berth deck surrounded by 14 large cabins for the officers while in the steerage were 12 more comfortable staterooms for the midshipmen, assistant engineers and other junior officers. Amidships were the crew's messes, which were larger and more comfortable than on contemporary American warships. Two bathrooms, considered a luxury, were located on each side just forward of the steering bulkhead while the sickbay and the capstans were forward. Below the berthdeck were the storerooms, shot-lockers, water tanks, etc. The spardeck was bombproof, having one-half-inch iron plates laid on the oaken beams and above them a five-inch pine deck. All the rigging deadeyes



[From a Lithograph by Endicott and Company.]

THE "GENERAL ADMIRAL."

**Figure 7. In 1882 *Harper's Weekly* published this view by the lithographers Endicott and Co., showing *General-Admiral* at sea. Note not only the taller funnel, but the loss of the fine clipper look as seen in *Frank Leslie's* drawings. How accurate then are artist's portraits of ships?**

were inside the bulwarks, which were plated. Beneath the water the bow was fitted with an armored beak for use as a ram, a result of the lesson of *Merrimac's* foray at Hampton Roads on 8 March 1862. [12]

The two modified Maudslay and Field (of Clydebank) engines fitted by the Novelty Iron Works were of the direct back-action type each giving 800 horsepower. The two cylinders were each 84 inches in diameter and the stroke of the piston 45 inches. On 18 lbs of steam at 45 revolutions she was able to do 12 knots. She carried 760 tons of anthracite in her bunkers and used 70 tons per diem at full speed. For the trans-Atlantic crossing additional fuel was carried in the lower holds. Ten engineers and 66 firemen and coal passers were carried. In the fireroom, which was 85 feet long and 9 feet 6 inches wide, were six horizontal watertube boilers set three to a side, each with six furnaces underneath. At the forward end was a large auxiliary boiler with two furnaces. Overhead in this space was slung a railway along which coal and ashes were moved. The engines were connected to the propeller by a 100-foot shaft resting on five bearings. The two-bladed screw itself was a nineteen-foot composite casting with 30 degrees pitch. For making a passage under sail the propeller could be hauled clear of the water to give near clipper-ship performance.

The pre-war price of these ships was $1,500,000 apiece. The HERALD reporter gave the equivalent wartime cost as $2,000,000. But whether this latter figure was in greenbacks or gold is uncertain. However, it is very doubtful if Webb was able to make a profit on these ships in view of the heavy inflation of prices, wages, and time while these ships were in his yard. [13]

On 12 November 1863 *Re d'Italia* left the Novelty Iron Works at the foot of 10th Street for the new Bremen Docks in Hoboken. It was a beautiful day, the ship answered her helm easily, and so Webb cast off the tugs and took her for a run down the Bay. With the Italian flag at the mizzen and the American at the main, she set off with a mixed crew of riggers and longshoremen as a strike deprived Webb of his usual sailors and the Italians

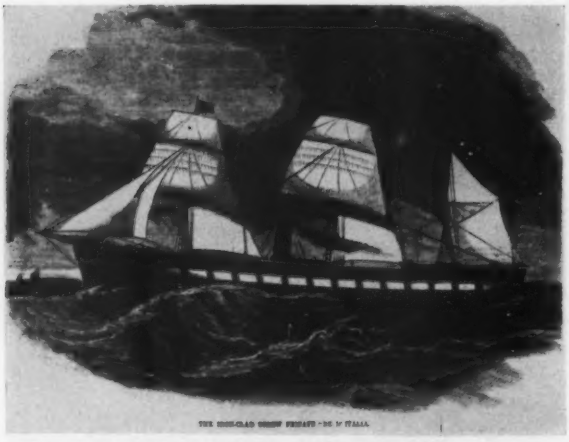


**Figure 8.** *Re d'Italia* **as seen by a** *Harper's Weekly* **artist. Neither her lines nor the set of her sails appears to conform to the descriptions of her which we have. Compare this portrait with Webb's own drawings of her.**

could not be entrusted with a vessel which they had not as yet accepted. On only four boilers she gradually increased from ten to twelve knots. At the Narrows she was put about like a pilot boat, as the HERALD reporter would have one believe, and headed back up the Bay past the admiring Russian and French warships anchored there. Upon arrival at Hoboken the Italians at once indicated their approval and acceptance became a foregone conclusion.

During the latter part of November, while the ship was coaled and provisioned and various minor adjustments made, the Italian officers were treated to a banquet at the Maison Dorée by the Italians of New York and in return not only did the Italian gentry visit the ship, but Webb gave a reception aboard. The invitations to the latter affair pointedly noted that *Re d'Italia* was the first ironclad frigate built in the United States. In commenting upon this the HERALD remarked that when the United States Navy Department left American builders alone, they could produce ships as good as any in the world. It certainly appears more than strange that the premier New York constructor should not have produced any Union warships during the war.

Despite rumors of the day, Webb received no further Italian orders. That country had by 1863 become sufficiently established to produce its own ships (or to buy them in Europe) and was proceeding to replace its inherited fleets with modern vessels.

On 25 December *Re d'Italia* moved down to quarantine and prepared for a trial trip to Fortress Monroe, Virginia, and return. At 7 a.m. on the 26th she got underway amid floating ice and headed for the bar, but as she began to roll in the tail of West Bank, the pilot refused to take her out and she anchored off Old Spit. The next day she weighed early and proceeded to sea. At 3 p.m. she increased to full speed. Shortly afterwards there was a great noise in the engine room and the engines stopped. After about an hour's work a piece of cast iron was located in the after cylinder of the second engine. It was found that a careless coppersmith had left a piece of wood in one of the steam pipes. On increasing to full speed this had been forced through the pipe and had sheared off the valves to the cylinder and these in turn dropped into the engine and broke the two bolts on the piston follower. Meanwhile sail had been set and the ship headed away from the Jersey coast. At 2 a.m. on Monday morning, after working all night, the forward engine was restarted and with canvas set fore and aft, she was headed in for the beach to stand by until 9 a.m. when she could cross the bar again. On one engine she was able to make six knots at 26 revolutions. At this moment a northeaster sprang up and the half-frozen Italian crew only poorly clewed up the sails, so that at 9 a.m. she was still 13 miles off Sandy Hook. She was set head to sea and rode easily, unlike most ironclads of the day refusing to bury her head in the seas. By 9 p.m. the wind had veered to southwest and sail was again set, but an hour later fog rolled in. Just after midnight, when the Italians were in charge, she ran aground. When the fog lifted an hour later, she was found to be some 200 yards off Wardell's Beach about a mile and a half from Long Branch, New Jersey. The Highlands lifeboat put out to her and messages were sent up to the city for assistance. She remained in that embarrassing position for a couple of days and then was floated off with assistance from tugs sent down by the underwriters and the Italian consul. On 7 January 1864 she went into the naval drydock at Brooklyn for examination.

*Re d'Italia* was found to have sustained no damage and was floated out of the drydock again on the 15th. She remained in the Navy Yard for another week before anchoring again in the North River on the 24th.

On 11 February she started on a trial trip to Hampton Roads to demonstrate her capacities to a USN mission, but owing to a gale could not get over the bar. On the 18th there was again floating ice all about and the ship herself had a six-inch ring of it at her waterline, yet she proceeded down the Bay to go to sea, but returned almost at once to her anchorage and then did speed trials in the Bay during which she sustained 12 knots on 5/16th regulator with four boilers providing 23 pounds steam. At five in the afternoon she passed over the bar, but the Italians decided that they were satisfied with her performance and that a trip to Fortress Monroe would be unnecessary and so after going ten miles east of the Cape May lightship, she was put about and anchored again off the Battery at 7 p.m. on the 19th, but shifted to Ford's Wharf shortly thereafter.

On 8 March she went down the bay to Quaran-

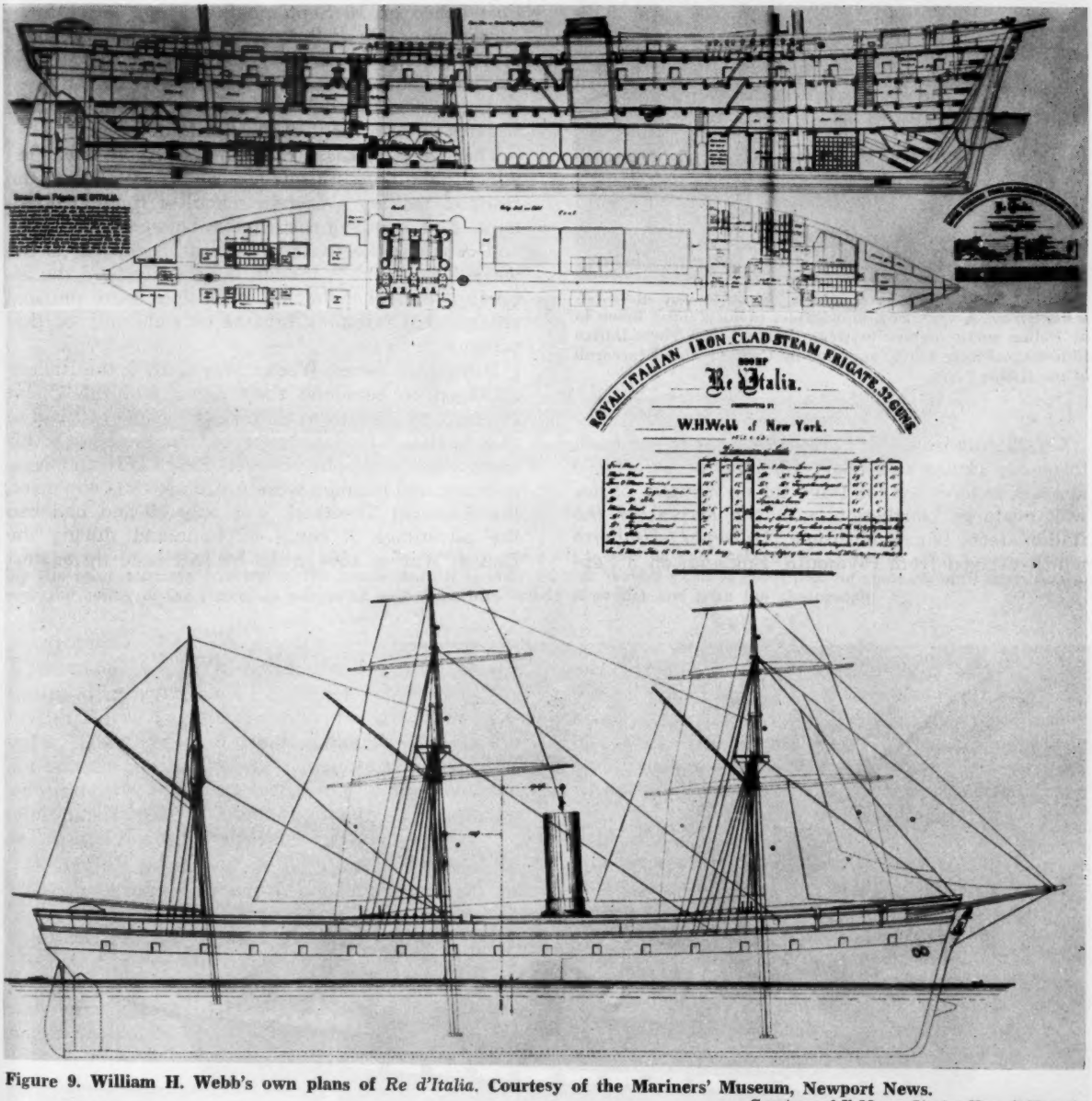
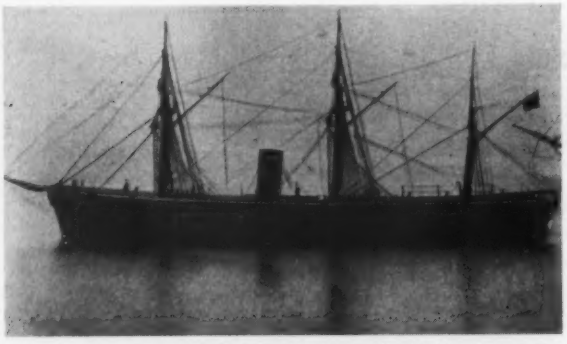



**Figure 9. William H. Webb's own plans of *Re d'Italia*. Courtesy of the Mariners' Museum, Newport News.**
Courtesy of Il Museo Storico Nav. di Venezia

tine and sailed on the tide early the next morning. After a fast passage she reached Gibraltar on 28 March after spending three days coaling at Madeira. For this voyage she generally used four boilers at 15 pounds pressure and covered 2,915 sea miles on 837 tons of coal and the remaining 595 miles from Madeira on 181 tons. The engineer reported that the propeller had passed through 643,489 revolutions on the first leg of the trip. On 4 April she left the Rock and was duly delivered to the Italians at Naples.

On 1 June the Italian transport *Volturno* arrived with the former crew of *Re d'Italia* sent back to collect her sister ship. She also carried furniture for *Re di Portogallo* (known also as *Dom Luigi de Portugallo*).

Little news of the second of the Webb ironclads was carried by local papers. It appears that once one of the type had been covered, even the shipping reporter lost interest. Arrivals of warships were commonly noted, but as clearances were based on customs house records, and warships did not have to clear, their departures were only occasionally included under "miscellaneous."



Courtesy of Il Museo Storico Nav. di Venezia

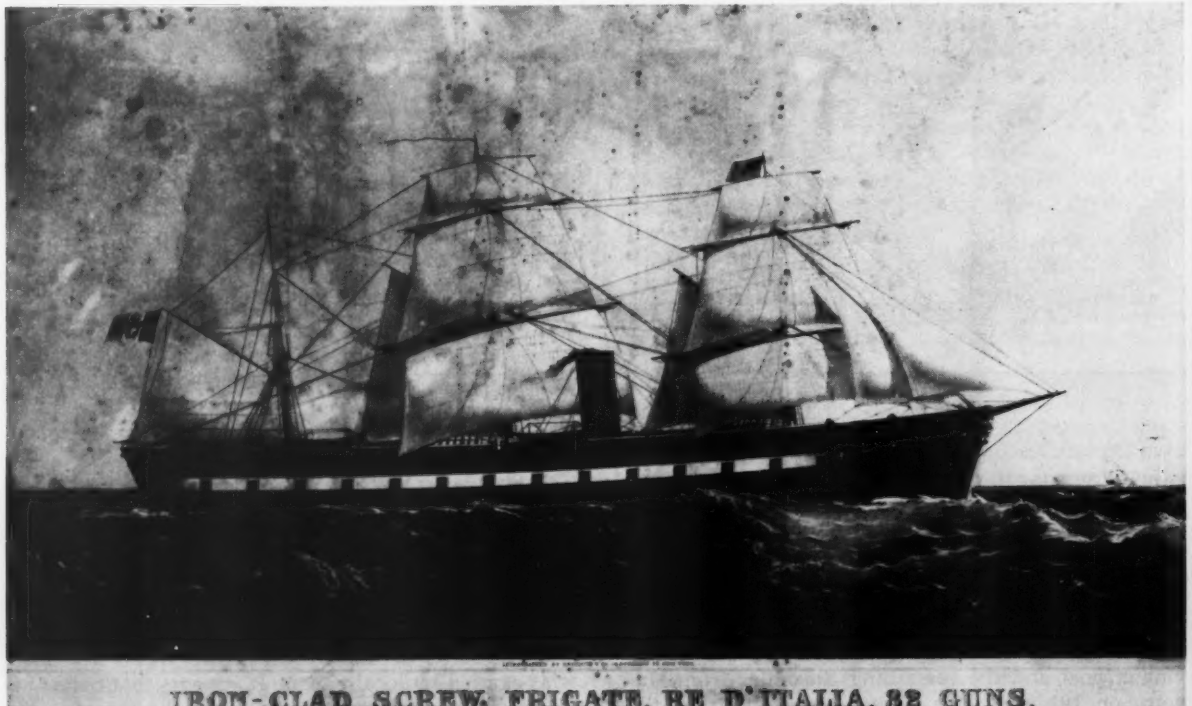
**Figure 10. A very rare photograph of *Re d'Italia* taken in an Italian port sometime between 1863 and 1866. These Italian illustrations were kindly supplied by Captain Aldo Fraccaroli of the Italian Navy.**

On 23 August *Re di Portogallo* went to sea for a three-day cruise and trials. Shortly thereafter she appears to have left for Italy, for no mention of her was made in connection with the arrival of the Italian steam frigate *Cruisepe* [*Guisepe?*] *Umberto* which arrived from Plymouth, England, on 3 September. And in the list of mail remaining at the US Post Office on 10 September was one letter for a carpenter on *Re di Portogallo* and five for the crew of *Volturno*.

What then became of these ships remains a mystery until 20 July 1866 when the two Webb ironclad frigates were present at the Battle of Lissa.

The battle of Lissa ranks among those incidents which have been misinterpreted in their day to the point of making a certain school of thought dominant. As a result of this contest between the Italian and Austrian fleets, the ram was regarded as the weapon of the day, though later analysis of the affair has indicated that the conditions were unusual enough that ramming became possible only on that occasion.

During the Seven Weeks' War of 1866, the Italians managed to persuade their aging admiral, Count Persano, to attempt to capture the island of Lissa in the Adriatic. Persano expected to be beaten, his fleets were still split between Sardinians and Neapolitans, and his men were untrained. His opponent, the Austrian Tegethoff, was only 39 and had had the advantage of being in command during the Danish War of 1864 when he had been up against




Courtesy of Il Museo Storico Nav. di Venezia

**Figure 11. A rare Currier and Ives print of *Re d'Italia*, copied from the same sketch used by *Harper's Weekly* showing her on trials or delivery with the American flag flying at the forepeak and the Italian ensign on the mizzen gaff.**

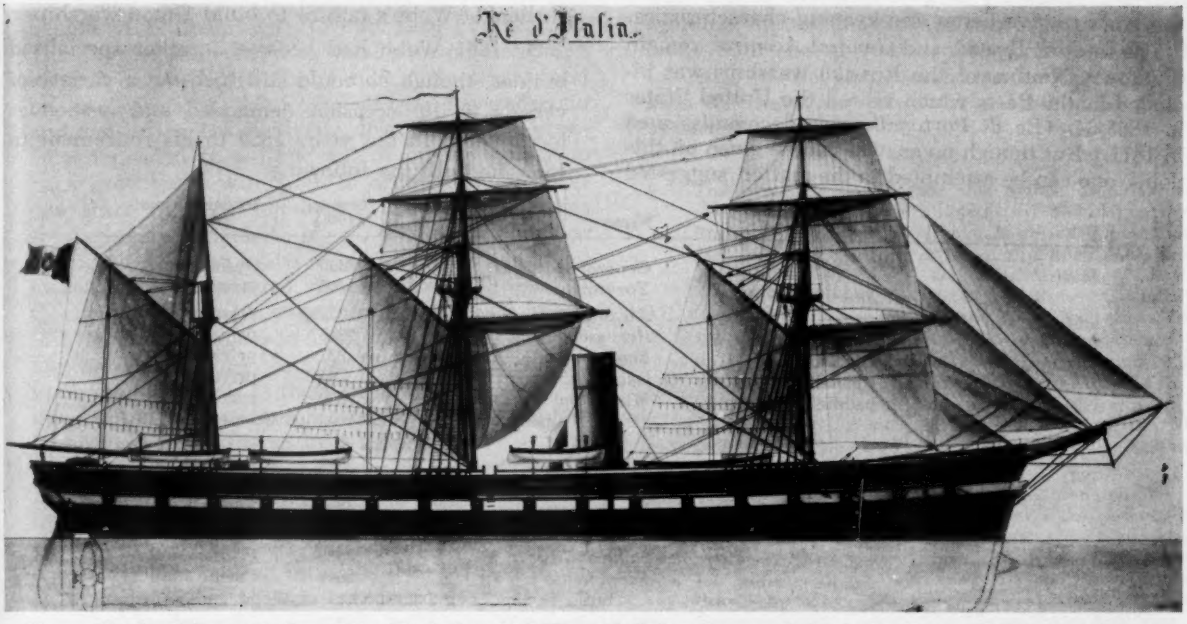



**Figure 12. The Italian sail plan of *Re d'Italia* in which the ports below the gun deck can be discerned. This view is probably the most accurate drawing of the vessel since it is believed that Webb's *Book of Plans* was not made up until later. Again, note the height of the funnel as compared with American artists' drawings and with the photograph.**

a maritime people. Although the Italian fleet was equipped with Armstrong muzzle-loading rifles (the British Royal Navy having abandoned breech-loading in 1864), Tegethoff decided, though his ships did not possess special prows, to ram as his own guns were inferior. In such a tactic he would present the minimum target to Italian gunners of whom he probably did not have a very high regard.

What then developed on the afternoon of 20 July 1866 was a battle in which an aggressive and inferior Austrian force charged the Italian fleet with excellent results. Persano was caught investing Lissa, but pulled out his ironclads and formed column and started across the front of the Austrians who were approaching in three wedges. But Persano's vacillation again took hold. He stopped *Re d'Italia* to shift his flag to the newly-arrived and long-awaited British-built double-turreted *Affondatore*. This action threw the line into confusion, especially since he had not really discussed battle tactics with his captains. During this first crisis for the Italians, Tegethoff broke through and struck the Italian *Palestro* and the Webb-built *Re d'Italia* glancing blows which did no damage. But shortly after this *Re d'Italia's* unprotected steering gear was put out of action. Suddenly Tegethoff's *Ferdinand Max*, 5200 tons, loomed through the smoke. The Italian captain could have escaped the blow by cracking on full speed as he was still underway. Instead, for, it is said, he wanted to board his opponent, he ordered full astern, and his ship was struck while dead in the water. At 11½ knots *Ferdinand Max's* unarmoured bow crashed through the armored port side of Webb's pride and made a hole clear into the engine room. Three hundred and eighty-one of the crew went down with their ship, while 168 were saved. Quite obviously, *Re d'Italia* need not have been lost if her captain had had any appreciation of her qualities. She was armored, had rifled guns (though it has been claimed that in the excitement and through lack of firing practice, the Italian gunners not infrequently omitted the shells!), and was faster than her opponents. Having the advantage of speed and firepower, she should have manouvered in the open, perhaps attempting to ram if an opportunity presented itself, but certainly not have sacrificed her advantage by attempting to board. [14]

In contrast to the loss of the first of the Webb-built frigates, the second came successfully through the action and received no injury from the Austrian battleship *Kaiser*, which attempted to ram her. The latter was in fact set afire and forced to withdraw. None of the ironclads were sunk by gunfire, and this caused contemporaries to place their emphasis upon the ram. Thus the ram bow, suggested in 1843 for a French frigate and adopted in 1859 in the new British ironclads *Defence* and *Resistance* and in the Southern *Virginia* (*Merrimac*) came to be standard equipment for larger naval vessels down until the end of the First World War. In its later years it was retained by designers not so much as a fighting point but as a means of providing additional buoyancy in

the bows to give better sea-keeping characteristics.

The fates of *Japanis* and *General-Admiral*, remain unknown. Neither of the Russian warships was included in the fleets which visited the United States in 1863-64. (*Re di Portogallo* was decommissioned in 1871.) But though no answer can be given on this point, one can be attempted in the matter, suggested earlier, of Webb's failure to build Union warships.

By 1861 Webb had become a rather specialized builder, though he could still turn out a variety of vessels if the occasion demanded and economics forced him. In the years 1859 to his retirement in 1869, he built the following:

| Date | Type | Name | Tonnage (1865) | Ownership and Remarks |
|---|---|---|---|---|
| 1859 | steam frigate | *General-Admiral* | 4600 | Russian navy |
| | paddle-steamer | *Yorktown* | 1400 | private |
| laid down in 1860 | packet | *Alexander H. Marshall* | 1232 | private |
| | bark | *Harvest Queen* | 315 | private |
| | brig | *Emma Dean* | 221 | private |
| | schooner | *Isaac Webb* | 95 | private |
| | paddle steamer | *Mississippi* | c.3200 | purchased by USN upon completion and renamed *Connecticut*, 18 July 1861. |
| 1861 | paddle steamer | *Constitution* | 3575 | Pacific Mail |
| | steam frigate | *Re d'Italia* | 4250 | Italian navy |
| | steam frigate | *Re di Portogallo* (Webb hull No. 124) | 4250 | Italian navy |
| 1862 | paddle steamer | *Golden City* | 3589 | Pacific Mail |
| | paddle steamer | *Sacramento* | 2647 | Pacific Mail build at the Long Island yard of Webb and Bell. |
| 1862 | steam ram | *Dunderberg* | 5250 | USN ordered her but as she was not completed until after the war she was sold to France when the American navy returned to sail. |
| 1863 | paddle steamer | *Colorado* | 3727 | Pacific Mail |
| | paddle steamer | *Henry Chauncy* | 2656 | Pacific Mail |
| | Sound steamer | *Bristol* | 2300 | private |
| | Sound steamer | *Providence* | 2300 | private |
| 1864 | bark | *James A. Borland* | 637 | private |
| | paddle steamer | *Montana* | 2676 | Pacific Mail build at the Long Island yard of Webb and Bell |
| 1866 | paddle steamer | *China* | 3836 | Pacific Mail ordered earlier as *Celestial Empire* and name changed before building commenced. |
| 1869 | packet | *Charles H. Marshall* | 1683 | private, the last square-rigger built in New York City and State. [15] (Webb hull No. 135) |

In addition to these ships, the records show that he fitted for service with the Union navy the schooner USS *Racer*, 252 tons, at a cost of $3,417 in 1861-62; the double-ended side-wheel steam ferryboat USS *Southfield*, 760 tons, at a cost of $4,-820.80, in 1861-62; and USSCP *Williams*, 210 tons, a schooner which was commissioned in January 1862. [16] None of these jobs was worth much to a man whose Pacific Mail steamers cost near a million dollars. The latter, incidentally, had walking-beam engines because the Novelty Iron Works, who made most of Webb's engines, had a large holding in the Pacific Mail.

From the information just presented it can be seen that Webb did virtually nothing for the Union navy during the great war of his day. Was he slighted by the government? Did the Secretary of the Navy or his Assistant dislike Webb? Far from it.

William Henry Webb was a Democrat who had been against the extension of slavery into the territories as early as 1848. More than that, he broke with the Democrats and was one of the founders of the Republican party. He was also one of the founders of the Pacific Mail Steam Ship Company which obtained a subsidy for the operation of a line to California in 1848. And a man who was closely connected with Webb, at least in 1866, in the affairs of the company was Gustavus Vasa Fox, sometime commander of a Webb-built steamer on the Panama run, then Assistant Secretary of the Navy. His superior was the Hartford editor, Gideon Welles. Welles was disliked by the New York newspapers because he had refused to make a certain influential gentleman a navy purchasing agent and the latter had stirred up the Press against him. For some purposes, it may have suited Welles, Fox, and Webb not to disabuse people as to the failure of the Navy Department to give Webb contracts other than for the minor repair work and for *Dunderberg*, an outstanding design.

But it would be false to suggest and imply that

the whole arrangement was concocted for the sole benefit of William Henry Webb, Esq. Far from it. The Pacific Mail played a vital part in the Union effort. The overland railroad did not then exist, and to send specie by that route was far too uncertain and dangerous, besides being slow. The Union economy depended to a large extent on the ability to back greenbacks with gold. In order to do so, after one scare by the Confederate raiders, specie was shipped from Panama to New York on British ships plying via Liverpool, just as in olden days American merchants had evaded mercantilistic Orders-in-Council by broken voyages until the Rule of War of 1756 was reapplied in 1806. The necessity of obtaining bullion thus justified Webb's concentration upon mail steamers as these generally took 14 to 20 months to construct and would be hard to replace if captured or destroyed by a raider.

Webb was also in constant touch, according to a letter he wrote to Dr. Benson Loping in 1883, with the Secretary of the Navy as to the character of vessels to be built and the organization of Navy Yards. He was himself an artist who refused to operate under the restrictions which the Navy Department's Constructors demanded. As a result, he designed several ships for the U. S. Navy which were never built. Prof. Ridgely-Nevitt has also pointed out that by mid-war the Webb yard was fully occupied, and in addition men and materials were probably by then too scarce to allow additional vessels for the Union Navy to be laid down. [17]

While this may be taken as a sufficient explanation for Webb's continued construction of paddle-steamers for his own company, it does not explain why the Federal government failed to expropriate the Italian frigates as the British in 1914 seized warships building in England for foreign powers. *Re d'Italia* and her sister would have made excellent raider-hunters with their relatively high steaming speed and excellent sailing characteristics. Yet, were the raiders worth two such vessels when weighed against the diplomatic situation of 1861-63?

The answer here was apparently decided in the negative, if, indeed, any conscious action was taken. Britain was by no means particularly friendly or sympathetic to the Northern cause. France was engaging in a number of acts of friendship for the Confederacy. Russia was in 1863 to show friendship for the United States, but for selfish reasons. Could the United States, then, afford to alienate the new state of Italy, already somewhat of a counterbalance in European affairs? Moreover, could the Republicans risk losing the many Italian votes in certain metropolitan areas, notably New York? No.

So Webb was able to pursue his professional work as were many others of his class and age at this time. Only, unlike many made rich by the war, he found his business ruined by it, and although he held on in shipping until 1872, he was approaching retirement for economic reasons by 1865. New York was unable to compete with European iron shipbuilding, and no major European power dared buy many of its naval vessels abroad. Add to this the influence of the Confederate raiders, and the reasons for the demise of Webb and his colleagues is apparent.

NOTES

[ 1] The principle sources for this article are: *Harper's Weekly, Frank Leslie's Illustrated Newspaper, New York Times, New York Herald; Historical Transactions, 1893-1945* of the Society of Naval Architects and Marine Engineers (New York), 1945, Fairburn, *Merchant Sail* (Center Lovell, Inc., 1945-1955), and Robert Greenhalph Albion's *The Rise of the Port of New York* (New York 1939). *The Dictionary of American Biography* articles on Webb, Fox and Welles are very variable and reflect the interests of the authors. Very little appears to be known of Webb other than as a shipbuilder, even by J. H. Morrison, *History of New York Shipyards* (New York 1909). See also *Harpers Magazine*, July 1882, 223-241. See also notes 3 and 9 below.

[ 2] Surprisingly little seems to have been done on William Webb outside of his connection with the packets and clippers. Fairburn has several sections on him and the article in *Harpers Magazine* (1882) was evidently written in consultation with him. His book of plans was drawn up after 1880 and published about 1890 (See Ridgely-Nevitt, Cedric, "The United States Mail Steamer *George Law*," *American Neptune*, IV, #4, (Oct. 1944), 307-308.

[ 3] For more elaborate discussions of the developments and difficulties in American shipbuilding see: Hutchins, J. G. B., *American Maritime Industries and Public Policy* (Cambridge, Mass., 1941) and his article in Fassett, F. G. (ed.), *The Shipbuilding Business in the United States of America* (New York, 1948) I, 14-61; Fairburn, William A., *Merchant Sail* (Center Lovell, Maine, 1945-1955) which is an enormous compilation, indexed, but not annotated; Albion, R. G., *The Rise of the Port of New York*, 1815-1860 and Kemble, John H., *The Panama Route 1848-1869* (Berkeley, 1943).

[ 4] For information on the earlier construction of Russian warships see Binder, Frederick M., "American Shipbuilding and Russian Naval Power, 1837-1846," *Military Affairs*, XXI, No. 2 (Summer 1957), pp. 79-84. Also *Harpers Magazine* as in Note 1.

[ 5] The actual tonnage of Webb's warships rather depends on the measurement system employed. Merchant ships were rated in tons burthen with the ton as 32 cubic feet until 1864. Carpenter's measure gave the tonnage in the actual cubic capacity of the hull converted into tons. Customs house measure, adopted by America in 1799, was based on the formula

$$\frac{(\text{Length}-3/5\ \text{Beam}) \times \text{Beam} \times \text{Depth of Hold}}{95}$$

and it was assumed that depth of hold was half the beam. Thus deep draft ships paid no more in dues than shallower models. In 1854 the British Merchant Shipping Act revised tonnage formulae in view of the 1849 repeal of the Navigation Acts and the decline in power of the British East India Company. The United States adopted this system in 1864. However, warships were abnormally heavy and a better system of measurement was required for rating them, so they commonly began to be described in terms of the tons of water they displaced, since tons burthen was in their case meaningless. This helps explain why the Italian frigates which Webb built were of 6100 tons fully loaded (displacement), 5500 tons upon completion (carpenter's measure, US style), and of 3500 tons customs house

formula, and of 4250 tons by the standard measurement adopted in 1864. See Fairburn, *Merchant Sail*, II, 1506–1507.

[ 6] U.S.S. *Niagara* was a steam screw frigate completed in New York in 1856, 329x55 feet, 4580 tons (1865) and was employed in 1858 in laying the first trans-Atlantic telegraph cable.

[ 7] See *Frank Leslie's Illustrated Newspaper*, 4 December, 1858, for detail description and cross-section drawings.

[ 8] See my article, "The Russian Fleet on the Eastern Seaboard, 1863-1864; a maritime chronology," *The American Neptune*, XX, No. 1. (January 1960), 49-61. For the visit to England see *The Illustrated London News*, 10 September 1859, 239, 240a-c.

[ 9] Henry Hall in his "Report on the Shipbuilding Industry of the U. S.," 47th Congress, 2nd Session, vol. 13, part 8, no. 42, gives somewhat different figures from Fairburn in *Merchant Sail*. It is mainly a problem of dating; some sources note the contract date, some the keel laying, some the launching and yet others the date the vessel cleared for service. Vessels laid down in 1863 were not completed in some cases until 1866. See also table below.

[10] Actually rams were fitted to British battleships laid down in 1859 and the famous Laird rams were in this tradition. See Oscar Parkes, *British Battleships, 1860-1950* (London 1957).

[11] H. W. Wilson's claim that these ships were built of greenwood and weak in their scantlings appears to fit into an European attitude, unfortunately not infrequently based on fact, but must be doubted in Webb's case as he had too much to lose by gaining a poor reputation abroad. If the ships were in poor condition at Lissa, the blame more likely rests with their crews. This would appear to be borne out by Wilson's statement that the armor belt in 1866 did not extend above the waterline. *Battleships in Action* (London 1926), I, p. 44.

[12] It is not possible to trace the origin of the ram bow, a feature of the earlier self-propelled warship—the galley, but some doubt must exist that the *Merrimac* really caused its adoption. By April 1862 the Royal Navy alone had 15 ram-fitted ships built or building. (See also note 10 above.) Neither of the contestants on 9 March 1862 were sea-going vessels.

[13] This may have occasioned the use of green woods; see note 11 above.

[14] For this battle see Wilson, *Battleships in Action*, I, 45-52.

[15] Vessels laid down in 1864 were in some cases still on the ways in 1865. *Montana* was not delivered to her owners until 1866. *China* was not delivered until 1867. After that there was a gap of some months before hull No. 135 was laid down. This was said to be the last Webb hull, but some sources give the date 1869 to *James A. Borland*, and she may have been the last vessel Webb built for the above compilation provides one hull too many according to numbers from *Re di Portugallo* (No. 124) to *Charles H. Marshall* (No. 135). One other steamer often credited to Webb, *Nevada*, was built in Brooklyn and only purchased by Webb on behalf of the North American Steam Ship Company in 1866. (See the various lists in Fairburn, and Henry Hall, heretofore cited, as well as Kemble, J. H., *The Panama Route, 1848-1869*, (Berkeley, Cal. 1943).

[16] *The Official Records of the Union and Confederate Navies*, II, i, 49, 76, 188, 212.

[17] Correspondence with Prof. Cedric Ridgely-Nevitt of the Webb Institute of Naval Architecture, 15 and 29 March 1960.

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BY LIEUTENANT COMMANDER L. O. CHIRILLO, USN

# *QUICK BALLASTING/DEBALLASTING IN LSD*

**THE AUTHOR**

*graduated from the U. S. Merchant Marine Academy in 1943, is licensed as a Chief Engineer since 1947, received an Associate of Arts Degree from the University of Louisville in 1950 and has completed three years of post-graduate training at the Massachusetts Institute of Technology in 1954. He has served in naval ships as engineering officer, in the Production and Planning departments of Naval Shipyards, in the Bureau of Ships and is currently assigned to the Staff of Commander Amphibious Force, U. S. Atlantic Fleet.*

WITHIN THE AMPHIBIOUS Forces the Landing Ship Dock (LSD), Figure 1, is the most versatile ship type and is considered by some to be the most valuable ship type. In addition to fulfilling the requirements of originally conceived missions and tasks, LSD have already demonstrated capabilities for Arctic resupply, for launching missiles, and for the support and operation of helicopters during an assault featuring vertical envelopment. Secondly, military commanders have already acknowledged that the combat operational readiness of LSD is directly related to the speed with which different conditions of trim may be obtained.

One principal LSD condition of operation is to ballast for trim by the stern in order to flood only the after portion of the well deck. Thus, landing craft of the LCU and LCM types may enter aft in order to load or discharge cargo. This mode of operation is termed Condition I which is schematically illustrated in Figure 2. As the sea state increases landing craft are hampered primarily by wave action within an LSD well. During rough weather it is the behavior of the sea within the well and not the beach surf which normally forces a halt of landing craft ferrying operations.

Waves within the well of about five foot height require that landing craft be actually landed before any transfer of cargo may be effected. However, the time required to deballast from Condition I is about thirty minutes. Conversely, ballasting to Condition I is of similar duration. Due to the erratic relative motion between landing craft and LSD during these relatively long periods the threat of serious damage or personnel injury often justifies postponement of

**Figure 1. Landing Ship Dock (LST 28 Class)**

operations. Therefore, in order to continue during increased sea states quicker means for ballasting/deballasting LSD are required. Minimizing the ballast/deballast period to no more than five minutes is considered significant and feasible.

Perusal of the functions of form for the LSD 28 Class hull indicates that as the after well deck floods the rate of reduction of the moment to trim one inch is extremely significant. This is due to the rapid loss of water plane area as the well deck submerges. Ultimately this moment reduces to one half of its original value. Therefore, for like moments twice the change in trim occurs when the after well deck is immersed as compared to a condition when the stern gate is closed. Advantage may be taken of this characteristic of LSD 28 Class hulls provided the after well deck remains immersed so as not to significantly increase the waterplane area during any of the cycle of operation.

Ships of the LSD 28 Class have two ballast tanks of at least 680 tons capacity each and ideally located 346 feet apart, i.e., tanks 6-36-OW and 6-208-OW. Starting from Condition I ballasting 6-36-OW and simultaneous deballasting of 6-208-OW would create a longitudinal moment of approximately 235,000 foot tons. Since the moment to trim one inch is 1085 foot tons for Condition I, the resultant decrease in trim would be about 217 inches. This is more accurately given as 204 inches in the Manual of Instructions for Operation of the Ballasting Systems, LSD 28 Class. The resulting new condition, illustrated in Figure 3, employs the latter, less optimistic number and would positively land craft of any type.

There remains only the establishment of a practical means of deballasting 680 tons of sea water from tank 6-208-OW and simultaneously ballasting 6-36-OW within five minutes. Two large capacity submersible pumps, one located in each tank would fulfill the needs provided each could handle 2.3

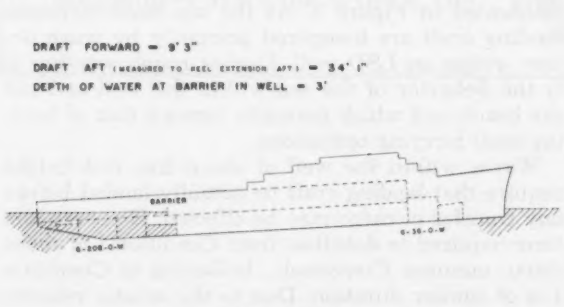
DRAFT FORWARD = 9' 3"
DRAFT AFT (MEASURED TO KEEL EXTENSION AFT) = 34' 1"
DEPTH OF WATER AT BARRIER IN WELL = 3'
BARRIER
6-208-O-W
6-36-O-W
CONDITION I

**Figure 2. Ballast condition permitting entry of Landing Craft.**

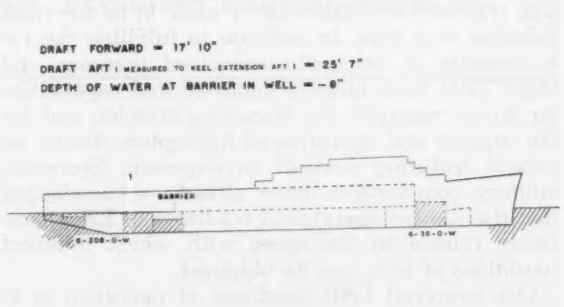
DRAFT FORWARD = 17' 10"
DRAFT AFT (MEASURED TO KEEL EXTENSION AFT) = 25' 7"
DEPTH OF WATER AT BARRIER IN WELL = -6"
BARRIER
6-208-O-W
6-36-O-W
NEW CONDITION

**Figure 3. Ballast condition that would positively land craft.**

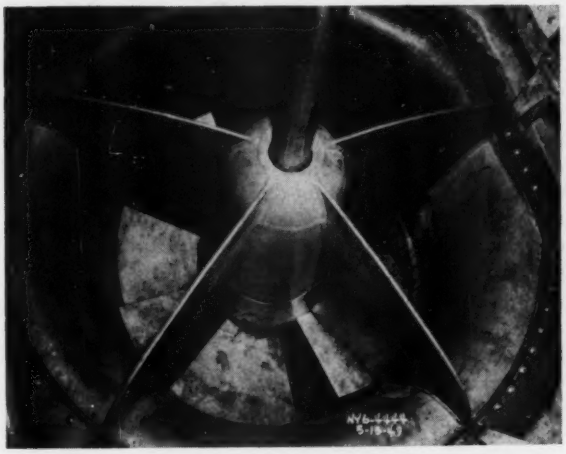

**Figure 4. Internal view of submersible pump water end.**

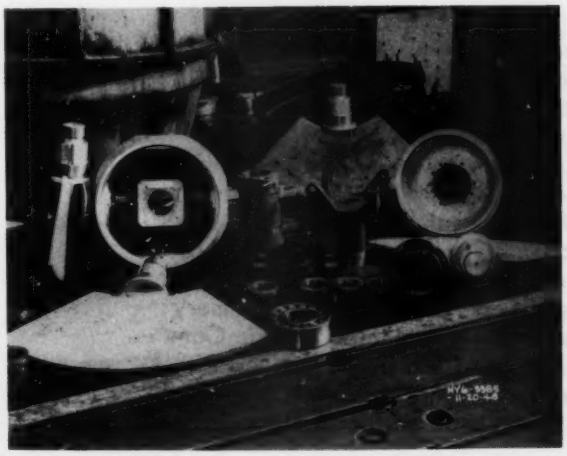

**Figure 5. Component parts of pump showing features of variable pitch propeller.**

tons of water ballast per second. Evidence of an almost similar requirement and feasibility was discovered in files pertaining to the installation of the Minorsky Stabilization Equipment in USS *Peregrine* (EAM-373). This equipment, for which development was initiated in 1948, utilized activated anti-rolling tanks. Water ballast was transferred very rapidly by variable-pitch propeller-type submersible pumps; essential features of one are illustrated in Figures 4, 5, and 6. During the trial this pump easily transferred 2.3 tons of ballast per second; the duct diameter was 24 inches.

Application of a similar submersible pump in an LSD ballast tank would necessitate consideration of a 25 foot head pressure with the resulting need for a prime mover of 230 horsepower. A representative electric motor, 3-phases, 440 volts, 60 cycles, would occupy an estimated cylindrical volume of 33-inch diameter and 63-inch length.

Other significant characteristics of a system employing submersible pumps for quick ballasting/deballasting in LSD would be:

(1) Complete independence from the existing LSD ballasting system.

(2) Each pump would be installed immediately adjacent to its sea chest with but one remote operated sea valve intervening. No piping system would be required since each would take immediate suction from the sea and would discharge directly into its ballast tank and vice versa.

(3) The remote controls for both pumps would be located together since their co-ordination would be required. When rapidly cycling between Condition I and the new condition, the use of sea valves is not anticipated. The ballast levels would be maintained during the relatively short intervals of landing craft loading/unloading or transit across the sill by continued operation of the high capacity pumps. Thus no time would be expended in opening and closing valves as would otherwise be required "to line up the piping system" for shifting ballast between two tanks.

Other methods have been considered for the rapid transfer of ballast in LSD; one being air displacement of ballast through flood holes in tank bottoms. Necessarily this scheme would require an additional piping system and associated compressors for large volumes of low pressure air. Vent valves would also be required; the rate of flooding would be controlled

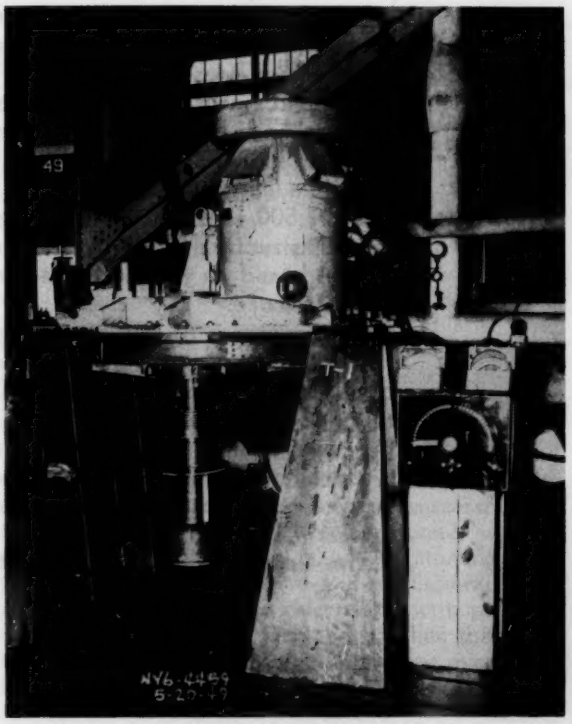

**Figure 6. Pump drive assembly.**

by the venting facilities installed. Other detrimental features would be the need to reinforce conventionally designed ballast tank structures and the presence of structurally undesired openings in the bottom plating. Further, the openings in the tank bottoms would complicate damage control procedures in the event that tanktop plates were damaged.

A third scheme would employ piping modifications to the existing ballasting systems in LSD that would permit "split plant" operation, i.e., employment of two ballast pumps to fill one tank while the remaining two pumps empty the other. A preliminary design study indicated that an estimated period of ten minutes would be required to achieve the desired change in trim. However, additional moments would be required for "lining up" the ballast system each time a ballast condition was to be changed.

As previously noted, LSDs have extremely significant roles in the modern Navy. Additional thought and effort which may ultimately achieve for them quick ballasting-deballasting procedures in the order of five minutes would significantly increase the combat operational readiness of Amphibious landing units.

REFERENCE

Manual of Instructions for Operation of the Ballasting Systems, LSD 28 Class (NAVSHIPS 348-0962).

## Launching of Britain's First Nuclear Submarine *Dreadnought*

The ***Dreadnought***, the Royal Navy's first nuclear submarine, was launched last month by H.M. the Queen at the Barrow-in-Furness shipyard of Vickers-Armstrongs (Shipbuilders), Ltd.

As originally planned, the ***Dreadnought*** was to have been fitted with a British-designed-and-built nuclear reactor, but in 1958 an agreement was concluded with the United States Government for the purchase of a complete set of propulsion machinery of the type fitted in the USS ***Skipjack***. This agreement has enabled the submarine to be launched far earlier than would otherwise have been possible. The supply of this machinery is being made under a contract between the Westinghouse Electric Corporation and Messrs. Rolls-Royce. The latter are also being supplied with design and manufacturing details of the reactor and with safety information and have now set up a factory in this country with a view to manufacturing similar cores.

With a length of 266 ft, a beam of 32 ft and a surface displacement of about 3,500 tons, the ***Dreadnought*** has a hull of British design both as regards structural strength and hydrodynamic features, although the latter are based on the pioneering work of the U.S. Navy in the ***Skipjack*** and ***Albacore***.

The reactor is of the pressurized-water type, which will drive a single shaft through steam turbines. Almost every electrical and mechanical part of the propulsion machinery is installed in duplicate so as to minimize the inconvenience of breakdowns. In addition, every control feature of the power plant and of the boat has been duplicated.

Accommodation for her complement of 11 officers and 77 ratings will be of a standard which it has been impossible to attain in any previous submarine.

The ***Dreadnought*** is expected to be commissioned in late 1962.

—THE MOTOR SHIP

# *BOOK REVIEWS & NOTICES*

## ADMINISTRATION OF THE NAVY DEPARTMENT IN WORLD WAR II

by

Rear Admiral Julius Augustus Furer, USN (Ret.)

Published in 1960 by U.S. Government Printing Office Price $6.50

Reviewed by

Vice Admiral R. E. McShane, USN (Ret.)

This book is a masterpiece. When one considers that many ramifications of the word "Administration" piled upon the complexities of that organization, the Navy Department in World War II, the task of compressing the history into one volume is one which would repel most men. Admiral Furer has done this, and done it superbly. This book is, in every sense, a masterpiece.

Starting with "An Overall Survey of the Naval Establishment" there is covered the individual segments of the Naval organization, with authoritative though compressed expositions of the various bureaus' problems and actions during the period in question.

Each chapter provides an adequate historical background which sets the stage for the recital of events occurring during the title period. By this device a surprisingly complete exposition of vital organizational and administrative history is provided.

After the recitation of the history of the organizational units the book concludes with a survey of broader functional matters. Under the chapter headings: "External Relations," "Naval Logistics," "Research and Development," "Industrial Mobilization and Material Procurement" and "Civilian Personnel" there is presented a quite comprehensive recital of these matters.

Among the Appendices is a remarkable "Chronology" which, in parallel columns, gives the timing of "Selected War Events," "U.S. Defense and War Measures" and "Navy Department Measures, Organization, and Policies." This device establishes in a graphic sequence the salient events of the war period. Standing alone it would give a structure to the years involved.

A splendid Index provides a key to any of the many subjects covered by this many-faceted story.

This is not a history to be read in successive sittings. It is a reference work primarily and, as such, should be of outstanding value to students and practitioners of organization and administration of naval affairs. It could be referred to with profit at frequent intervals, and particularly when that urge to "reorganize" or "modernize" practice overcomes those in authority. It may be that this volume will reveal that "it was tried before and found wanting for the following reasons."

## JANE'S FIGHTING SHIPS 1960-1961

Compiled and Edited by
Raymond V. B. Blackman, A.M.R.I.N.A., A.I. Marie
Supplied in U.S.A. by
The McGraw-Hill Book Company, Inc.
330 West 42nd Street, New York 36, N.Y.

No one with the slightest interest in naval ships needs an introduction to Jane's Fighting Ships. This has been a worldwide standard reference book ever since the first edition was published by Fred T. Jane in 1897.

In this edition, the 63rd year of issue, some 10,000 warships of the navies of 75 countries are listed and described with the greatest detail which security rules of the various countries permit. There are more than 2500 photographs and scale drawings of which 470 are new to this issue.

As usual, a foreword summarizes the world situation as regards warships. It points out the great and growing need for a standard nomenclature for ships because construction and design trends no longer fit what a few short years ago were conventional type names. For example, ships which their countries call frigates range from 600 to 6000 tons; destroyers from 5000 to 1000 tons. There has been a growing tendency to lengthen type names of ships by including characteristics of weaponry and propulsive power, for example: Nuclear Powered, Guided Missile Destroyer, because the simple word "Destroyer" is no longer adequate. It is noted that "battleship" was derived from "line of battle ship" and "destroyer" from torpedo boat destroyer." A plea is made for a return to first principles and to seek one-word type names, probably using the criterion of function or role.

Inside the back cover, the editor has placed a table of comparative strength in 34 classes of ships of the 53 strongest naval countries. This table does not include ships under construction and makes no distinction between ships in reserve, which are included, and ships in active service. Thus the United States is credited with possession of 2788 ships, combined Navy and Coast Guard. On the same basis, using round estimated figures for most types, the USSR is credited with 2955. The classes in which Russia is reported as having greater strength than the U.S. are:

- Leaders 30 to 13
- Submarines 450 to 157 (nuclear propelled not included)
- Patrol vessels and submarine chasers 125 to 103
- Motor torpedo boats and fast patrol boats 500 to none
- Coastal minelayers 12 to 5
- Ocean and fleet minesweepers 225 to 157
- Coastal minesweepers and hunters 275 to 30
- Inshore minesweepers and sweeping boats 300 to 50
- Survey ships 50 to 15
- Training ships 16 to 2

The United States leads in numbers of all other types.

In the nuclear submarine category, the count is 17 U.S. to 3 USSR but the Russian figure is indicated in other places in the book as being indefinite. The U.S. is shown with a total of 50 nuclear submarines, 33 of which are building or projected. It is estimated that the USSR program consists of 6 ships with status ranging from 3 in service, 1 on trials and 2 under construction to 1 on trials, 1 building and 4 projected.

According to Jane's there are but 201 warships in the world which are rated larger than destroyers or frigates and 114 of these are classed as cruisers. Of the 78 aircraft carriers of all sizes, 58 are U.S., 19 belong to other western countries and 1 to India.

In addition to presenting a wealth of authentic information and much more which is acknowledged to be somewhat speculative, Jane's Fighting Ships 1960-1961 as usual offers a wide variety of data for the enjoyment of the statistician.

## FUEL CELLS

Edited by George J. Young
Published in 1960 by Reinhold Publishing Corporation
430 Park Avenue, New York 22, N. Y.
152 pages of text and illustration
Price $5.75

Reviewed by C. F. Viglotti
Electrical Branch, Bureau of Ships

This book is based on the papers presented at a symposium held by the Gas and Fuel Chemistry Division of the American Chemical Society at the 136th National meeting in Atlantic City in September 1959.

The fuel cell is an electrochemical device in which chemical energy can be continuously converted to direct current electrical energy. The word "continuously" is the key word in this definition which sets fuel cells apart from primary and secondary batteries. In electrochemical batteries the energy which can be obtained before the battery is either discarded or recharged is limited by the quantity of active materials incorporated in the battery structure. The fuel cell is a convertor which will continuously deliver electrical energy so long as a fuel and oxidant are fed into the cell. A more descriptive name for the fuel cell is that it is a continuous feed primary battery.

In 1893, W. Grove first demonstrated the principle of the fuel cell. It was until after World War II before any intensive research was made on fuel cells. In the interim the heat engine received much of the scientific effort in the energy conversion field. The efficiency limitations of heat engines and need for conserving fossil fuels has caused an upsurge in fuel cell research and developments.

In this volume workers in the field have contributed a group of papers covering the various fuel cell systems being currently investigated. The chapter headings which are listed below will illustrate the scope of these papers:

1. Introduction, H. S. Liebhafsky and D. L. Douglas.
2. The Hydrogen-Oxygen (Air) Fuel Cell with Carbon Electrodes, Earl Kordesch.
3. Catalysis of Fuel Cell Electrode Reactions, G. J. Young and R. B. Rozelle.
4. Electrode Kinetics of Low-Temperature Hydrogen-Oxygen Fuel Cells, L. G. Austin.
5. The High Pressure Hydrogen-Oxygen Fuel Cell, F. T. Bacon.
6. High-Temperature Fuel Cells, G. H. J. Broers and J. A. A. Ketelaar.
7. Carbonaceous Fuel Cells, H. R. Chambers and A. D. S. Tentram.
8. Nature of the Electrode Processes in Fuel Gas Cells, E. Gorin and H. L. Recht.
9. Molten Alkali Carbonate Cells with Gas-Diffusion Electrodes, Daniel L. Douglas.
10. Summary of Panel Discussion.

Each paper presents a complete discussion of the respective fuel cell system including experimental results, performance and life data, details of construction, application and future prospects. These papers may be considered as authoritative and possibly the best source for data and information on fuel cells since the authors are some of the major workers in the field.

Because these papers were prepared for presentation before a scientific group they will be of greatest value to those working in fuel cells and to the reader with a background in electrochemistry. This book is not recommended for the lay-reader who may have had his curiosity aroused by the articles on fuel cells which have recently appeared in some of the popular periodicals. It is, however, a book that fulfills a ned in a field which is attracting the interest of many industrial research organizations.

## BOOKS RECEIVED

"An Illustrated Dictionary of Plumbing Terms" by Evan Berry, published by Philosophical Library, Inc. 15 E. 40th St., New York 16, N.Y. 244 pages, $6.00

"Saline Water Conversion." A collection of papers, published by The American Chemical Society, 1155 16th St., N.W., Washington 6, D.C. 246 pages, $5.85

"Servomechanisms" by P. L. Taylor, published 1 February 1961 by Longsmans, Green & Co., Inc., 119 West 40th St., New York 18, N.Y. 418 pages. Text Edition $8.50

"Hydrodynamics" by Garrett Birkhoff, published by the Princeton University Press, Princeton, N.J. 184 pages, $6.50

# *CHANGES IN MEMBERSHIP*

ADDITIONS TO MEMBERSHIP

We are happy to announce that the following have joined the Society since the publication of the November 1960 issue of the JOURNAL.

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Barron, George B. ..... *Civil*
Belling, Theodore H. ..... *Asso.*
Bent, Robert M. ..... *Civil*
Bish, Howard P. ..... *Civil*
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Mulford, John Willets ..... *Asso.*
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Oatley, H. B. ..... *Asso.*
Oliver, Malcolm P. C. ..... *Asso.*
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Walbridge, John B. ..... *Civil*
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Zanot, Raymond J., CAPT, USN ..... *Naval*

### DROPPED FROM ROLLS

We regret exceedingly to report that in accordance with the By-Laws it was necessary to drop 125 members from our rolls on 31 December 1960 because of arrearage of one years dues.

## DEATHS

**It is with deep regret that we announce that since the last Journal we have received notice of the deaths of the following members:**

Brierly, R. C., LCDR, USNR (Ret) ..... *Naval*
Craig, Edward C., CAPT, USN (Ret) ..... *Naval*
Droescher, L. A. ..... *Civil*
Keenan, George J. ..... *Civil*
Klein, H. S., CAPT, USN ..... *Naval*
McNamara, John, Jr., ENS, USNR ..... *Naval*
Powelson, W. V. N., LT, USN (Ret) ..... *Life*
Sharp, George G. ..... *Civil*
Slocum, Stephen E. ..... *Honorary*
Smith, Fred E., LCDR, USN (Ret) ..... *Naval*
Stransky, Gustave ..... *Asso.*
Templeton, Thomas H., CAPT, USN (Ret) *Naval*
Vieweg, Walter V. R., RADM, USN ..... *Naval*

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The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

**Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.**

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Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

# *ASSOCIATION NOTES*

## PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

## NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

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For Volume 63 (1951) and later address the Society.

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# ASNE FINANCIAL STATEMENTS 1960

## Statement of Income & Expenditures

### EXPENDITURES

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| Publication | | |
| Printing | 26,157.92 | |
| Engraving | 2,866.75 | |
| Manuscripts | 6,364.78 | |
| Postage | 1,003.31 | |
| Commission & Discount | 2,176.67 | 38,569.43 |
| Salaries | | 16,977.56 |
| General Expense | | 3,667.40 |
| Awards | | 435.46 |
| Rent | | 3,100.00 |
| Bad Debts & Miscellaneous | | |
| Members dropped for non-payment of dues | 1,290.00 | |
| Depreciation on Furniture | 411.41 | |
| Misc. Sales, Subs. | 159.85 | 1,861.26 |
| Social Security | | 473.32 |
| Retirement Funds | | 3,600.00 |
| | | 68,684.43 |

### INCOME

| | | | |
|---|---|---|---|
| Publication | | | |
| Advertisements | 14,640.54 | | |
| Regular Dues | 34,172.50 | | |
| Junior Dues | 45.00 | | |
| Sales | 635.52 | | |
| Subscriptions | 18,507.31 | 68,000.87 | |
| Interest on Investments | | 2,608.50 | |
| Banquet 1960 | | 571.83 | 71,181.20 |
| | | NET PROFIT | 2,496.77 |

## BALANCE STATEMENT

| | | | |
|---|---|---|---|
| **Assets, January 1, 1960** | | | 56,984.74 |
| **Assets, December 31, 1960** | | | |
| Cash | | 3,236.01 | |
| Petty Cash | | 72.44 | |
| | | 3,308.45 | |
| Accounts Receivable | | | |
| Advertisements | 1,236.88 | | |
| Dues | 20.00 | | |
| Sales | 85.25 | | |
| Subscriptions (1960 & in advance) | 10,855.40 | 12,197.53 | |
| Investments | | | |
| Columbia Savings & Loan | 10,000.00 | | |
| Equitable Savings & Loan | 10,000.00 | | |
| Enterprise Savings & Loan | 10,000.00 | | |
| First Federal Savings & Loan | 5,000.00 | | |
| Liberty Savings & Loan | 5,000.00 | | |
| Northwestern Fed. Savings & Loan | 5,000.00 | | |
| Perpetual Building & Loan | 10,000.00 | | |
| U.S. Defense Bonds, Series K | 5,000.00 | 60,000.00 | |
| Furniture | | 2,248.30 | |
| Manuscripts Paid in Advance | | 2,820.00 | |
| Expenses Paid in Advance (Stationery, Billheads, etc.) | | 518.87 | |
| ASNE Award Die | | 80.00 | |
| | | 81,173.15 | |
| Liabilities (Accounting Only) | | | |
| Advertisements Paid in Advance | 161.70 | | |
| Dues Paid in Advance | | | |
| Regular | 601.75 | | |
| Junior | 5.00 | | |
| Subscriptions Paid in Advance | 14,471.65 | | |
| Accounts Payable | | | |
| Printing | 6,432.50 | | |
| Sales | 19.04 | —21,691.64 | |
| **Net Assets December 31, 1960** | | | 59,481.51 |
| | | **Net Profit** | 2,496.77 |

Respectfully submitted

s/ J. E. Hamilton, Secretary-Treasurer

Audited and Found Correct 23 January 1961

s/Gilbert S. Frankel)
)
s/Frank C. Jones ) Audit Committee
)
s/Donald E. Redmon)

Securities in Society's safe deposit box at American Security and Trust Company, Washington, D. C. examined and found as reported herein.

s/Frank C. Jones

## APPLICATION FOR MEMBERSHIP

## IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

**(See reverse side for required qualifications for various classes of membership)**

Date_____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____ $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

### For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

### For Civil Membership

Name _____
(First) (Middle) (Last)

Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

### For Associate Membership

Name _____
(First) (Middle) (Last)

Rank, if Commissioned Officer of U.S. Army or of foreign military or Naval service _____

Business connection and position _____

Recommended by (one member) _____

_____

*Signature of Applicant*

Address for JOURNAL and Mail

_____

_____

MAIL TO SECRETARY-TREASURER

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 403, Continental Building

1012 14th St., N.W. Washington 5, D.C.

**Company Memberships Not Available**

## QUALIFICATION FOR MEMBERSHIP

Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

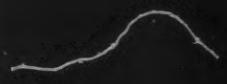
Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Commissioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transferring to regular membership in the appropriate category.

Associate and Junior Members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $10.00, payable on 1 January in advance, of which $8.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

## COMPANY MEMBERSHIPS NOT AVAILABLE



# Secretaries of the

# AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

**Captain J. E. Hamilton, U. S. Navy Retired, Secretary-Treasurer**

**Commander Joe W. Thornbury, U.S.N., Assistant Secretary-Treasurer**

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## Past Secretaries

1889 *P. A. Engineer R. S. Griffin, U. S. Navy*

1890 *Assistant Engineer W. M. McFarland, U. S. Navy*

1891 *Assistant Engineer Emil Theiss, U. S. Navy*

1892-93 *P. A. Engineer W. M. McFarland, U. S. Navy*

1894-95 *P. A. Engineer R. S. Griffin, U. S. Navy*

1896-97 *P. A. Engineer F. C. Bieg, U. S. Navy*

1898 *P. A. Engineer W. M. McFarland, U. S. Navy*

1899 *Chief Engineer A. B. Willits, U. S. Navy*

1900 *Lt. Comdr. A. B. Willits, U. S. Navy*

1901 *Lieutenant B. C. Bryan, U. S. Navy*

1902 *Lieutenant C. W. Dyson, U. S. Navy*

1903 *Lt. Comdr. John R. Edwards, U. S. Navy*

1904 *Lieutenant M. E. Reed, U. S. Navy*

1905 *Lieutenant W. W. White, U. S. Navy*

1906 *Lieutenant C. K. Mallory, U. S. Navy*

1907-08 *Lt. Comdr. T. C. Fenton, U. S. Navy*

1908-10 *Lieutenant H. C. Dinger, U. S. Navy*

1911 *Commander U. T. Holmes, U. S. Navy*

1912 *Lieutenant John Halligan, U. S. Navy*

1912 *Lt. Comdr. E. L. Bennett, U. S. Navy*

1913 **Lieutenant O. L. Cox, U. S. Navy**

1914 *Lt. Comdr. H. C. Dinger, U. S. Navy*

1915-16 *Lieutenant A. T. Church, U. S. Navy*

1917 **Lt. Comdr. J. O. Richardson, U. S. Navy**

1917-19 *Lt. Comdr. F. W. Sterling, U. S. Navy*

1919-21 **Commander J. S. Evans, U. S. Navy**

1921-23 **Commander S. M. Robinson, U. S. Navy**

1924-25 **Commander Bryson Bruce, U. S. Navy**

1926 **Commander A. M. Charlton, U. S. Navy**

1927-28 **Commander H. B. Hird, U. S. Navy**

1928 **Captain O. L. Cox, U. S. Navy**

1929-30 *Commander H. T. Smith, U. S. Navy*

1931 **Captain O. L. Cox, U. S. Navy**

1932 **Commander H. F. D. Davis, U. S. Navy**

1933-34 **Commander H. B. Hird, U. S. Navy**

1935-36 *Commander C. S. Gillette, U. S. Navy*

1936-38 **Commander Roger W. Paine, U. S. Navy**

1938-40 **Lt. Comdr. Guy Chadwick, U. S. Navy**

1940-44 **Captain J. E. Hamilton, U. S. Navy**

1945 **Commander R. T. Sutherland, Jr., U. S. Navy**

1945-48 **Captain F. W. Walton, U. S. Navy**

1948-51 **Captain J. E. Hamilton, U. S. Navy**

## Past Assistant Secretaries

1939-40 **Lieutenant Milo B. Williams (C.C.) U. S. Navy**

1941-44 **Lt. Comdr. Robert T. Sutherland, Jr., U. S. Navy**

1945 **Captain F. W. Walton, U. S. Navy**

1945-47 **Commander Floyd B. Schultz, U. S. Navy**

1947-49 **Commander C. H. Meigs, U. S. Navy**

1949-50 **Commander Frank C. Jones, U. S. Navy**

1951-59 **Captain Robert B. Madden, U. S. Navy**

1959-60 **Commander Charles N. Payne, U. S. Navy**

## Clerk and Administrative Assistant

1908-58 **Mr. Arthur G. Fessenden**

1958- **Miss Ruth M. Leonard**

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*Names in italics deceased

FEBRUARY 1961

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